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PROBABILITIES OF ONE-INCH SNOWFALL THRESHOLDS FOR THE UNITED STATES

H. C. S. THOM

Office of Climatology, U. S. Weather Bureau, Washington, D. C.

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ABSTRACT

Following previous work, climatological statistics and computational methods are presented for obtaining the quantiles of first one-inch 24-hour snowfall. These are employed in computing the .05, .10, .30, .90 quantiles for 164 United States and Alaskan first-order Weather Bureau stations.

1. INTRODUCTION

The one-inch snowfall threshold is defined as the first day in fall or winter on which *one inch or more* of snowfall has occurred. This is expressed as a date; i. e., by day and month. It is a typical climatological threshold variable since it expresses the time at which some critical value is passed.

The climatological analysis for such snowfall thresholds was developed by Thom [1] and applied to various values of the threshold. He found that threshold date is approximately normally distributed for years in which a threshold value occurs. If the threshold value occurs every year or with a probability approaching one, the threshold date distribution is a normal distribution on day number counted from July 1. If the threshold does not occur every year, it was found that the threshold distribution could be expressed as a mixed distribution. This is a mixture of years with no threshold occurrence and years with threshold occurrence, the threshold occurrences being further distributed as to date. This theory led to expressions for the threshold quantiles and the mean threshold date.

The one-inch threshold quantiles are given for .05, .10, .30, and .90 probability for 164 cities in the United States and Alaska. These should be useful in many types of planning problems. In particular, they will be of interest to snow tire manufacturers, snow removal equipment manufacturers, and those who are responsible for the removal of snow from streets and highways. The raw data employed in this study were originally compiled for a manufacturer of snow tires.

2. THE THRESHOLD DISTRIBUTION

The general threshold distribution function was given in [1] as

$$G(t)=pF(t)+q(t>365) \tag{1}$$

Here $G(t)$ is the probability of a threshold occurrence before date t, p is the probability of a year with a threshold occurrence, $F(t)$ is the probability of a threshold occurrence before t in years which have threshold occurrences, and $q(t>365)$ is the probability of no threshold occurrence and is included only after $F(t)$ approaches one. The non-occurrence of a threshold here is formally equivalent to the occurrence of a threshold outside the dated threshold population, or outside the 365-day year allowed for thresholds to occur and therefore not considered as an occurrence.

Although the result is the same, the threshold distribution may be developed in a somewhat different fashion as follows: According to the development above, $F(t)$ is the probability of a threshold occurring before t, hence, $1-F(t)$ is the probability of a threshold after t. We may

now express the distribution function for a threshold after t as

$$H(t)=p[1-F(t)]+q. \tag{2}$$

Hence, the distribution function for a threshold before t is

$$G(t)=1-H(t)=1-p[1-F(t)]-q=pF(t) \tag{3}$$

This becomes identical with equation (1) when we add q, the probability of no threshold occurring, and meets the condition that a distribution function must approach unity as t increases without limit. Equation (3) may also be looked upon as a conditional probability; i. e., the product of the probability of a threshold occurring by the probability that it will occur before t, given that a threshold has occurred. Graphical illustrations of the frequency distribution and distribution function are given in [1]. Equation (3) will be found convenient for the computation of the quantiles.

In reference [1] the hypothesis that $F(t)$ is a normal distribution function was examined and the hypothesis of normality found to be well met by the samples studied. Similar procedures were applied in examining the normality hypothesis for this much larger sample of stations on the one-inch threshold. As was to be expected, statistical analysis showed no general significance departure from normality. Hence, we have again assumed t to be approximately normally distributed with estimated mean $\bar{t}$ and standard deviation s.

3. COMPUTATION OF THE QUANTILES

Since the quantiles are inverse functions of the variate, they may be obtained by inverting equation (3). Writing $N(t)$ for $F(t)$ to indicate a normal distribution, equation (3) becomes

$$N(t)=G(t)/p.$$

Inverting the function on the left gives

$$t=N^{-1}[G(t)/p] \tag{4}$$

In order to use the standard normal tables, t must be converted to the standardized variate $x=(t-\bar{t})/s$. Substituting this in (4) we find

$$(t-\bar{t})/s=N^{-1}[G(x)/p].$$

Hence

$$t_G=sN^{-1}[G(x)/p]+\bar{t} \tag{5}$$

where t_G is a quantile with probability $G(x)$.

Using the climatological series of one-inch thresholds the mean $\bar{t}$ and the standard deviation s were estimated in the usual fashion. Since p is the probability of such a threshold occurrence, it was estimated by the ratio of the number of years with thresholds to the total number of years of record n. These are shown for each station in table 1.

The procedure for obtaining the quantiles may be best illustrated by an example. Taking the first station in the table, Anniston, Ala., we find $\bar{t}=2/2$ (i. e., Feb. 2), $s=32.1$, and $p=0.2889$. Converting $\bar{t}$ to day number gives 217 (the exact value was 216.6). For the .05 quantile $G(x)=.05$. Substituting these values in equation (5) yields

$$t_{.05}=32.1N^{-1}(.05/.2889)+216.6$$

$$=32.1N^{-1}(.173)+216.6$$

Referring to a standard normal table and keeping in mind that .173 is a probability, we find $N^{-1}(.173)=-0.94$. Substituting this value yields

$$t_{.05}=32.1(-.94)+216.6=186.$$

Converting this day number to date we find $t_{.05}=1/2$, or January 2, which agrees with table 1. It is clear that any quantile may be readily obtained by this procedure.

It should be noted that since p is the amount of probability in the actual occurrence of a threshold, the quantile probabilities cannot exceed this amount. Hence, when the computed quantile probability exceeds p there is no entry in the table. No stations were included where the probability of a threshold occurrence was less than 0.10. Each quantile $t_{.05}$, etc., of table 1 is the date for which the probability of one inch or more in 24 hours occurring earlier in date is the quantile probability. Thus, for Burlington, Iowa, as seen in the table, the probability of a threshold occurrence before 10/23 is 0.05, before 11/2 is 0.10, before 11/21 is 0.30 and before 1/6 is 0.90. Also in other terms, the first one-inch 24-hour snowfall will occur on the average once in 20 years before 10/23, once in 10 years before 11/2, about once in 3 years before 11/21, and in nine out of ten years before 1/6.

ACKNOWLEDGMENTS

The author wishes to express thanks to Mr. C. K. Vestal for calling attention to the tabulated data, to the National Weather Records Center for fitting the distributions, and to Mr. Maurice Kasinoff for making the final calculations.

REFERENCE

1. H. C. S. Thom, "Climatological Analysis of Snowfall Thresholds," *Archiv für Meteorologie, Geophysik, und Bioklimatologie, Serie B*, vol. 8, No. 2, 1957, pp. 195–201.

Table 1.—*Statistics on one-inch threshold for snowfall for 164 first-order stations, listed alphabetically by states. The entries under $\bar{t}$ and t_a indicate "month/date"*

Station	$\bar{t}$	s	n	p	$t_{.05}$	$t_{.10}$	$t_{.30}$	$t_{.90}$
Anniston, Ala	2/2	32.1	45	0.2889	1/2	1/20		
Birmingham, Ala	1/24	35.3	51	.4118	12/14	12/31	2/15	
Tucson, Ariz	1/10	25.0	21	.3810	12/13	12/25	1/30	
Fort Smith, Ark	1/19	29.2	51	.7843	12/6	12/17	1/10	
Little Rock, Ark	1/15	33.2	51	.6471	11/29	12/12	1/12	
Eureka, Calif	1/23	25.9	51	.1176	1/18	2/19		
Red Bluff, Calif	1/6	18.8	51	.4118	12/15	12/24	1/18	
Denver, Colo	10/27	18.5	51	1.0000	9/26	10/3	10/17	11/19
Grand Junction, Colo	12/2	23.3	51	.9804	10/25	11/2	11/20	1/3
Pueblo, Colo	11/16	24.2	51	1.0000	10/8	10/16	11/4	12/17
Hartford, Conn	12/9	19.4	47	1.0000	11/7	11/14	11/29	1/3
New Haven, Conn	12/11	20.5	51	1.0000	11/7	11/15	11/30	1/6
Wilmington, Del	12/22	25.6	43	.9535	11/11	11/20	12/10	2/1
Atlanta, Ga	1/17	34.8	51	.2745	12/17	1/5		
Augusta, Ga	1/17	36.9	51	.1176	1/10	2/24		
Macon, Ga	1/22	37.7	51	.1569	1/5	2/5		
Boise, Idaho	12/6	21.3	51	.9804	11/1	11/9	11/25	1/4
Pocatello, Idaho	11/21	25.0	51	1.0000	10/11	10/20	11/8	12/23
Cairo, Ill	12/30	29.5	51	.9412	11/12	11/23	12/16	2/19
Chicago, Ill	12/6	18.7	51	1.0000	11/5	11/12	11/26	12/30
Moline, Ill	12/11	21.0	20	.9500	11/7	11/14	12/1	1/14
Peoria, Ill	12/12	24.5	45	1.0000	11/1	11/10	11/29	1/12
Springfield, Ill	12/17	27.8	51	1.0000	11/1	11/11	12/2	1/21
Evansville, Ind	12/24	28.5	51	.9020	11/9	11/20	12/12	3/16
Fort Wayne, Ind	12/7	23.0	40	.9750	10/31	11/8	11/26	1/9
Indianapolis, Ind	12/15	23.3	51	1.0000	11/7	11/15	12/3	1/14
Terre Haute, Ind	12/19	24.1	39	1.0000	11/9	11/18	12/6	1/19
Burlington, Iowa	12/4	25.7	49	1.0000	10/23	11/2	11/21	1/6
Charles City, Iowa	11/26	20.1	51	1.0000	10/24	10/31	11/15	12/22
Davenport, Iowa	12/8	23.8	51	1.0000	10/30	11/8	11/26	1/8
Des Moines, Iowa	12/5	21.9	51	1.0000	10/30	11/7	11/24	1/2
Dubuque, Iowa	12/1	20.2	51	1.0000	10/28	11/5	11/20	12/26
Keokuk, Iowa	12/13	22.2	47	1.0000	11/6	11/14	12/1	1/10
Sioux City, Iowa	11/24	21.1	51	1.0000	10/21	10/28	11/13	12/21
Concordia, Kans	12/15	32.8	51	.9412	10/23	11/4	11/30	2/9
Dodge City, Kans	12/10	28.9	51	.9608	10/24	11/4	11/26	1/23
Topeka, Kans	12/12	27.5	51	1.0000	10/28	11/7	11/28	1/17
Wichita, Kans	12/18	24.4	51	.9608	11/9	11/17	12/6	1/25
Lexington, Ky	12/15	25.4	51	.9804	11/3	11/12	12/2	1/19
Louisville, Ky	12/22	28.1	51	.9412	11/6	11/17	12/9	2/8
Shreveport, La	1/15	25.8	51	.3333	12/19	1/2	2/17	
Eastport, Maine	11/25	16.8	51	1.0000	10/29	11/4	11/17	12/17
Portland, Maine	11/30	14.7	51	1.0000	11/6	11/11	11/22	12/19
Baltimore, Md	12/26	30.6	51	.9804	11/6	11/17	12/10	2/7
Washington, D. C	12/22	28.9	51	1.0000	11/5	11/15	12/7	1/28
Boston, Mass	12/14	18.1	51	1.0000	11/14	11/21	12/5	1/6
Nantucket, Mass	12/25	21.6	51	1.0000	11/19	11/27	12/14	1/21
Alpena, Mich	11/17	16.4	51	1.0000	10/21	10/27	11/8	12/8
Detroit, Mich	12/1	17.1	51	1.0000	11/3	11/9	11/22	12/23
Escanaba, Mich	11/21	17.3	51	1.0000	10/24	10/30	11/12	12/13
Grand Rapids, Mich	11/21	14.3	48	1.0000	10/28	11/2	11/13	12/9
Lansing, Mich	11/22	17.0	41	1.0000	10/25	10/31	11/13	12/14
Marquette, Mich	11/2	15.3	51	1.0000	10/8	10/14	10/25	11/22
Sault Ste Marie, Mich	11/3	13.3	51	1.0000	10/12	10/17	10/27	11/20
Duluth, Minn	11/13	21.2	51	1.0000	10/9	10/17	11/2	12/10
Minneapolis, Minn	11/20	22.3	51	1.0000	10/15	10/23	11/9	12/19
Meridian, Miss	1/29	30.2	51	.2353	1/5	1/23		
Vicksburg, Miss	1/20	23.1	51	.3333	12/27	1/8	2/19	
Columbia, Mo	12/19	29.3	51	.9804	10/31	11/11	12/4	1/28
Kansas City, Mo	12/12	27.7	51	1.0000	10/27	11/6	11/27	1/16
St. Joseph, Mo	12/16	32.5	41	.9756	10/24	11/5	11/30	1/31
St. Louis, Mo	12/21	23.6	51	.9804	11/12	11/21	12/9	1/22
Springfield, Mo	12/22	29.4	51	1.0000	11/4	11/14	12/7	1/29
Billings, Mont	11/2	24.1	38	1.0000	9/24	10/3	10/21	12/3
Butte, Mont	10/10	23.4	12	1.0000	9/2	9/10	9/28	11/9
Great Falls, Mont	10/19	25.0	11	1.0000	9/8	9/17	10/6	11/20
Havre, Mont	10/29	30.5	51	1.0000	9/9	9/20	10/13	12/7
Helena, Mont	10/19	24.8	51	1.0000	9/8	9/17	10/6	11/20
Kalispell, Mont	11/14	23.1	51	1.0000	10/7	10/15	11/2	12/13
Missoula, Mont	11/24	26.6	51	.9804	10/11	10/21	11/10	12/31
Lincoln, Nebr	12/7	25.5	51	1.0000	10/26	11/4	11/24	1/8
North Platte, Nebr	11/24	27.5	51	1.0000	10/10	10/20	11/10	12/29
Omaha, Nebr	12/4	25.5	51	1.0000	10/23	11/2	11/21	1/6
Valentine, Nebr	11/22	38.0	51	1.0000	9/21	10/4	11/2	1/10
Reno, Nev	12/8	33.2	46	1.0000	10/14	10/26	11/21	1/19
Winnemucca, Nev	12/4	27.7	51	1.0000	10/20	10/27	11/20	1/8
Concord, N. H	11/26	15.6	51	1.0000	11/1	11/6	11/18	12/16
Atlantic City, N. J	1/3	27.8	51	.9608	11/19	11/29	12/20	2/15
Trenton, N. J	12/19	22.4	51	.9608	11/12	11/20	12/8	1/22
Albuquerque, N. Mex	12/24	28.3	31	.9355	11/8	11/19	12/10	2/12
Roswell, N. Mex	12/25	30.7	47	.9362	11/6	11/17	12/11	2/18
Albany, N. Y	12/2	14.1	51	1.0000	11/9	11/14	11/25	12/20
Binghamton, N. Y	11/26	15.8	51	1.0000	10/31	11/5	11/17	12/16
Buffalo, N. Y	11/19	17.6	51	1.0000	10/21	10/28	11/10	12/12
Canton, N. Y	11/13	18.6	44	1.0000	10/13	10/20	11/3	12/7
New York, N. Y	12/19	17.5	51	.9804	11/20	11/27	12/10	1/12
Oswego, N. Y	11/22	13.9	51	1.0000	10/30	11/4	11/15	12/10
Rochester, N. Y	11/21	14.5	51	1.0000	10/28	11/3	11/14	12/10
Syracuse, N. Y	11/16	13.6	49	1.0000	10/24	10/29	11/9	12/3
Asheville, N. C	12/26	30.7	49	.8980	11/8	11/19	12/13	
Charlotte, N. C	1/16	32.6	51	.6863	11/30	12/13	1/11	
Greensboro, N. C	1/7	29.1	23	.6522	11/27	12/9	1/4	
Hatteras, N. C	1/12	24.5	51	.2157	12/25	1/9		
Raleigh, N. C	1/12	30.6	51	.7451	11/28	12/9	1/5	
Wilmington, N. C	1/20	29.5	51	.2941	12/23	1/8		
Bismarck, N. Dak	11/7	26.2	51	1.0000	9/25	10/5	10/25	12/11
Devils Lake, N. Dak	11/9	20.4	46	1.0000	10/7	10/14	10/30	12/5
Fargo, N. Dak	11/17	25.1	51	1.0000	10/7	10/16	11/4	12/19
Williston, N. Dak	11/11	26.7	51	1.0000	9/28	10/8	10/28	12/15
Akron-Canton, Ohio	11/27	21.1	20	1.0000	10/23	10/31	11/16	12/24
Cincinnati, Ohio	12/16	23.5	51	.9804	11/8	11/17	12/4	1/18
Cleveland, Ohio	11/28	19.2	51	1.0000	10/27	11/3	11/18	12/22
Columbus, Ohio	12/13	25.6	51	.9804	11/1	11/11	11/30	1/18
Dayton, Ohio	12/13	26.1	40	.9750	11/1	11/10	11/30	1/19
Sandusky, Ohio	12/8	20.7	51	.9804	11/4	11/12	11/27	1/6
Toledo, Ohio	12/7	18.5	51	1.0000	11/7	11/14	11/28	12/31
Oklahoma City, Okla	1/8	31.3	51	.8627	11/20	12/1	12/26	
Tulsa, Okla	12/28	15.6	12	1.0000	12/2	12/8	12/20	1/17
Baker, Oreg	11/23	19.0	50	1.0000	10/23	10/30	11/13	12/17
Portland, Oreg	1/10	29.8	51	.7843	11/26	12/7	1/1	
Medford, Oreg	1/4	26.5	40	.6750	11/26	12/7	12/31	
Roseburg, Oreg	1/11	21.8	51	.6078	12/12	12/21	1/11	
Erie, Pa	11/13	16.2	51	1.0000	10/17	10/23	11/5	12/4
Harrisburg, Pa	12/13	20.6	51	1.0000	11/9	11/16	12/2	1/8
Philadelphia, Pa	12/22	24.1	51	1.0000	11/13	11/22	12/10	1/22
Pittsburgh, Pa	12/3	22.2	51	1.0000	10/28	11/5	11/22	1/1
Reading, Pa	12/13	18.4	47	1.0000	11/13	11/19	12/3	1/6
Scranton, Pa	12/3	18.8	51	1.0000	11/2	11/9	11/23	12/27
Block Island, R. I	12/28	24.0	51	1.0000	11/18	11/27	12/15	1/27
Providence, R. I	12/15	21.1	47	1.0000	11/10	11/18	12/4	1/11
Columbia, S. C	1/11	36.6	51	.2157	12/15	1/7		
Greenville, S. C	1/16	25.8	34	.5588	12/12	12/23	1/18	
Huron, S. Dak	11/22	26.0	51	.9804	10/11	10/20	11/9	12/28
Rapid City, S. Dak	11/8	25.7	51	1.0000	9/27	10/6	10/26	12/11
Chattanooga, Tenn	1/5	28.6	51	.6471	11/26	12/7	1/3	
Knoxville, Tenn	1/3	33.1	51	.8627	11/12	11/25	12/21	
Nashville, Tenn	1/6	34.8	51	.8431	11/13	11/26	12/25	
Abilene, Tex	1/15	31.6	51	.6471	12/1	12/14	1/12	
Amarillo, Tex	12/10	33.5	51	.9412	10/17	10/29	11/24	2/5
Austin, Tex	1/22	33.6	50	.1800	1/3	1/18		
Dallas, Tex	1/11	27.4	38	.5000	12/7	12/19	1/18	
Del Rio, Tex	1/17	23.0	45	.2000	1/1	1/17		
El Paso, Tex	1/4	27.3	51	.5490	11/29	12/11	1/8	
Fort Worth, Tex	1/13	26.0	51	.5490	12/9	12/20	1/16	
Salt Lake City, Utah	11/15	18.7	51	1.0000	10/16	10/23	11/6	12/9
Modena, Utah	11/26	25.8	50	1.0000	10/15	10/24	11/13	12/29
Burlington, Vt	11/18	14.9	45	1.0000	10/25	10/30	11/11	12/7
Northfield, Vt	11/11	17.1	43	1.0000	10/14	10/21	11/3	12/3
Cape Henry, Va	1/16	25.2	51	.7647	12/9	12/19	1/9	
Lynchburg, Va	1/2	30.8	51	.9804	11/12	11/24	12/17	2/13
Norfolk, Va	1/12	27.2	51	.8431	12/1	12/11	1/2	
Richmond, Va	1/2	28.7	51	.9216	11/17	11/28	12/20	2/28
North Head, Wash	1/17	28.2	49	.5714	12/10	12/22	1/19	
Seattle, Wash	1/2	29.3	51	.7255	11/20	12/2	12/27	
Spokane, Wash	11/27	22.1	51	1.0000	10/21	10/29	11/15	12/25
Tacoma, Wash	12/26	30.1	51	.8039	11/10	11/22	12/17	
Tatoosh Island, Wash	1/2	28.2	48	.6250	11/23	12/5	1/1	
Walla Walla, Wash	12/15	26.8	51	.9608	11/1	11/11	12/2	1/25
Yakima, Wash	12/11	23.7	32	1.0000	11/2	11/11	11/29	1/10
Elkins, W. Va	11/23	24.4	51	1.0000	10/14	10/23	11/10	12/24
Parkersburg, W. Va	12/12	25.4	51	1.0000	11/1	11/10	11/29	1/14
Green Bay, Wis	11/27	21.4	51	1.0000	10/23	10/30	11/16	12/24
La Crosse, Wis	11/26	19.7	51	1.0000	10/24	10/31	11/15	12/21
Madison, Wis	11/30	19.2	51	.9804	10/29	11/5	11/20	12/26
Milwaukee, Wis	12/3	19.5	51	1.0000	11/1	11/8	11/23	12/28
Cheyenne, Wyo	10/23	25.4	51	1.0000	9/11	9/20	10/10	11/24
Lander, Wyo	10/18	25.3	51	1.0000	9/6	9/15	10/4	11/19
Sheridan, Wyo	10/26	23.9	44	1.0000	9/17	9/25	10/13	11/25
Yellowstone Park, Wyo	10/12	18.0	37	1.0000	9/12	9/19	10/2	11/4
Anchorage, Alaska	10/26	15.8	18	1.0000	9/30	10/5	10/17	11/15
Fairbanks, Alaska	10/12	16.3	26	1.0000	9/16	9/21	10/4	11/2
Juneau, Alaska	11/9	15.4	34	1.0000	10/15	10/20	11/1	11/29
Ketchikan, Alaska	12/9	33.0	18	1.0000	10/16	10/28	11/22	1/21
Nome, Alaska	10/26	14.8	20	1.0000	10/2	10/7	10/19	11/14

Weather Notes

NOCTILUCENT CLOUDS IN ALASKA, JULY 27-28, 1957

Noctilucent clouds were observed at Anchorage, Alaska, on the night of July 27-28, 1957. The clouds were first observed at 2350 AST on July 27. They faded from sight completely at 0300 AST on July 28. The clouds were not observable at WBAS Fairbanks (too much light), or at WBAS Northway (low clouds in area).

The following report is extracted from a memorandum from Donald P. Hutchins of Gulkana, Alaska, where the noctilucent clouds were observed by CAA personnel:

> At 12:10 a. m. AST, July 28, 1957, extremely high clouds of the noctilucent type were observed in the north quadrant, bearing 320° to 050° (magnetic) from the station with an angular elevation from 10° to 65° above the northeastern horizon. The greatest concentration of color display appeared to be at azimuth 340° (magnetic) at an elevation angle of 23° above the horizon. Color varied with elevation. Starting at 10° immediately above the smoke layers the color was a light blue-gray and darkened gradually into a deep purple at 60° to 65°. Throughout the blue colors were streaks or slashes of silver which was bordered and spotted with a light pink-gold color resembling brush strokes on a painting. There was a faint smokey-white edge to the overall cloud layer on the western side. After one hour of observation there seemed to be a definite westward movement to the cloud mass. A lower layer of altocumulus moved in rapidly from the southwest and prevented further observation after 1:45 a. m.

As observed at Anchorage by WBAS personnel, the noctilucent clouds were a pale bluish-white near the horizon, changing gradually to a purplish-blue toward the zenith. Several described the clouds as having a distinct silvery appearance but without iridescence; in any event, there were numerous silver streaks. The total mass subtended 70° to 90° of azimuth and 5° to 15° of elevation.

When first observed at 2350 AST, the observer estimated an azimuth bearing of 030°–090° (true) subtending an elevation angle of about 10°. A detailed theodolite observation taken at 0042 AST by Observer David L. Bentley follows:

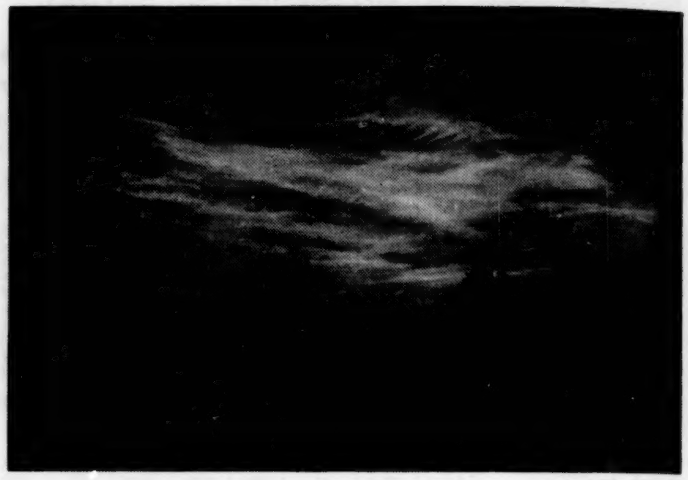
Azimuth	*Minimum Elevation*	*Maximum Elevation*
0°	6.5°	10.2°
010	[1] 1.4	10.3
020	[1] 1.4	11.6
030	[1] 3.0	10.9
040	[1] 3.5	12.3
050	5.1	12.0
060	3.7	11.4
070	5.5	7.8
078.9	7.2	----

[1] Lowest possible angle because of natural obstructions.

Mr. Bentley also sighted on the bright spot near the center of the cloud mass as follows:

Time	*Azimuth*	*Elevation*
0055 AS	30.0°	8.6°
0056	30.0	8.7
0057	30.0	8.8
0058	30.0	8.9
0059	30.0	9.0
0100	30.0	9.1
0101	30.0	9.2

Observer Richard W. Glommen stated that he first noticed the clouds at 0015 to 0030 AST; he observed the same type clouds on several successive nights in July or August of 1953 at Fairbanks, Alaska. At 0130 AST, Mr. Glommen made the following observation using the theodolite: The cloud mass extended through an azimuth from 337° to 075° (true) with a maximum elevation angle of 27° and minimum elevation angle of 6°.



James W. Zoller

Figure 1.—Photograph of noctilucent clouds, taken 4½ miles east of International Airport, Anchorage, Alaska, July 1957.

Although the readings do not permit unique determination of the height of the clouds, rough estimates can be made. Based on roughly concurrent readings at Gulkana and Anchorage, the brightest portion of the cloud mass is estimated to have been 200 to 300 miles from Anchorage, in the neighborhood of Big Delta, at 0042 AST. (Note that azimuth readings from Gulkana are magnetic and must be adjusted to true north to conform with Anchorage readings; magnetic declination at Gulkana is 29° E.) Triangulation, using a distance from Anchorage of 200 miles and an elevation angle of 8°, gives a height of 53 km.; using 250 miles, which is probably closer to the actual distance, the height is estimated at 68 km. Later, when the cloud had moved west, an elevation angle of 16° and distance of 150 to 200 miles give an estimated height of 73 to 97 km.

Mr. James W. Zoller took pictures of the clouds from his home, approximately 4½ miles east of International Airport, Anchorage. One of his prints which portrays actual conditions most closely is reproduced in figure 1. His photographs were taken on Plus-X film at one second with the aperture opening varying from *f* 16 down to *f* 2. Mr. Zoller was unable to obtain a reading on the exposure meter, so it was necessary to experiment to determine the proper exposure. Lack of correct exposure information prevented him from taking pictures every half hour to show cloud movement or changes. The best pictures were taken at *f* 8 to *f* 11 at one second; since this is much faster than the times proposed in official instructions, we feel this information is valuable for future photography of abnormally bright noctilucent clouds. A small bank of high altocumulus or cirrus can be seen in the lower left corner of the picture. Of particular interest are the long parallel silvery streaks aligned along the direction of motion with smaller parallel streaks at right angles, which correspond almost exactly with Vestine's comment (in the "Survey of Data and Theoretical Analysis of the Upper Atmosphere," Final Report, Institute of Geophysics, Uni-

(Continued on page 281)

INTENSIFICATION OF A TROPICAL STORM AT HIGHER LATITUDE

The Case of September 14–15, 1904

WALTER S. SPUHLER

Hydrometeorological Section, U. S. Weather Bureau, Washington, D. C.

[Manuscript received November 26, 1956; revised July 23, 1957]

ABSTRACT

The tropical Low of September 14–15, 1904, is selected as a case for the study of a weak tropical Low intensifying as it moves to higher latitudes. By the use of barograms, thermograms, and autographic wind records, the storm track is reconstructed and hourly surface maps are drawn. The barograms, thermograms, and wind records are combined on single charts for individual stations showing that the increase in winds is associated with the inflow of cold air. The central pressure of the Low is determined and found to decrease as the Low moves northward. Filling of the Low begins after it moves north of 39.5° N.

1. INTRODUCTION

The relatively weak tropical cyclone that moved inland over eastern South Carolina early on the morning of September 14, 1904, was selected for study as an outstanding example of a weakened tropical storm which later intensified at a higher latitude. As the storm first moved inland the maximum 10-minute-average winds observed were about 40 m. p. h. Moving in a northeasterly direction, the storm crossed North Carolina, Virginia, Delaware, and New Jersey, and passed just off the coast of Rhode Island and Massachusetts. The 10-minute-average wind increased to 72 m. p. h. at Delaware Breakwater, Del. (with a reported 1-minute-average wind of 100 m. p. h.) shortly after the storm center passed. Although the damage was light to moderate in the Carolinas and Virginia, heavy losses were suffered in crops, buildings, and shipping from Delaware and New Jersey to Massachusetts. The reported loss to shipping was estimated to be $1,000,000 and the loss on land was estimated at $2,000,000. There were 14 lives lost. These figures are taken from newspaper reports of the time.

2. SOURCE OF DATA

Triple-register records and barograph and thermograph traces were the basic source of weather information. Monthly weather records (W. B. Form 1001) and original weather maps of the Weather Bureau were also used. Ten-minute-average windspeeds were extracted from the triple-register records and speed graphs were drawn. Wind direction graphs were also made from the triple-register records. The station pressure was read from the barograph trace and reduced to sea level. The original monthly weather records (W. B. Form 1001) were used to obtain the sea level correction; at stations where Form 1001 was not available but the barograph record was, the original weather maps of the Weather Bureau were used to obtain the sea level pressure correction.

3. METHODS OF APPROACH

The first step in the storm study was to determine, as accurately as possible, the hourly positions of the storm. The track of the storm (fig. 1) was drawn from just off the coast of South Carolina to just off the coast of Massachusetts.

Various methods were used to determine the storm track. The time of lowest pressure at a station was used

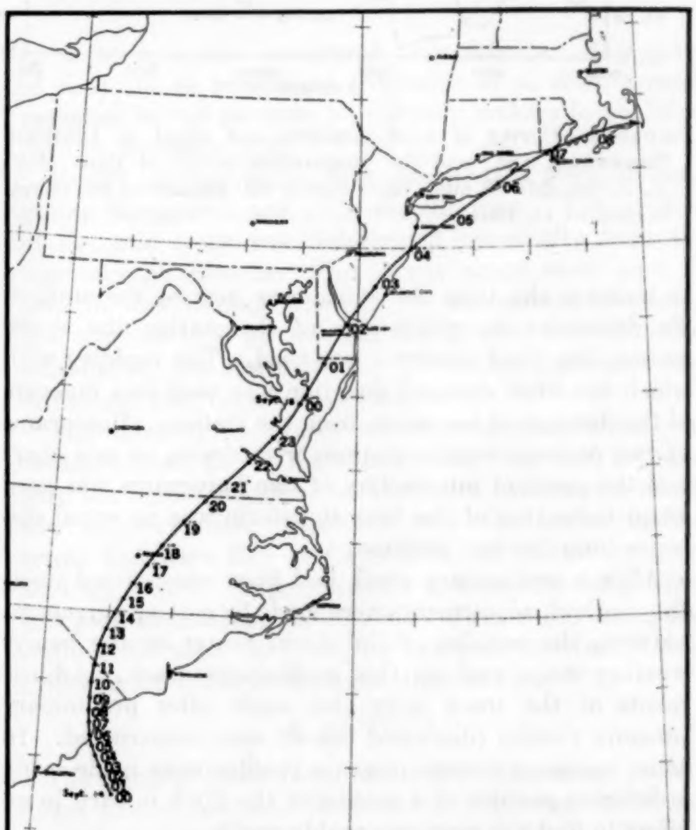


FIGURE 1.—Track of the tropical Low of September 14–15, 1904.

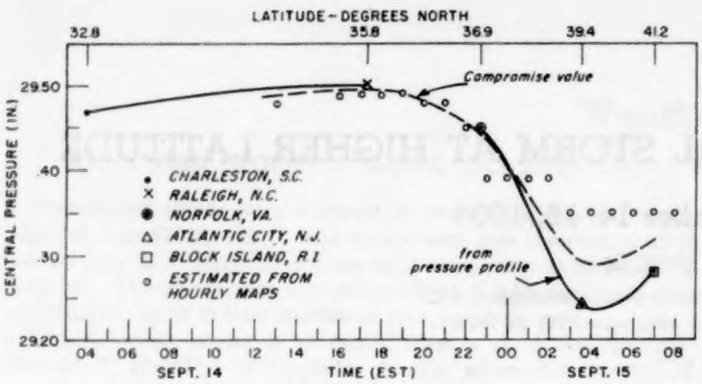


FIGURE 2.—Central pressure of the storm.

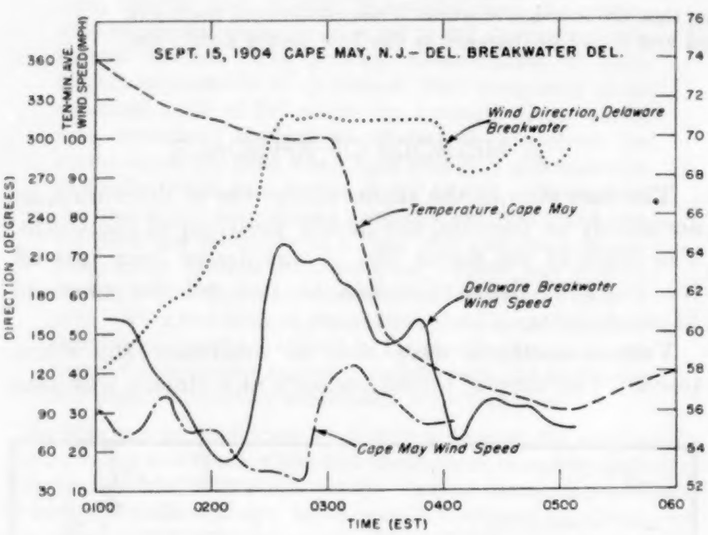


FIGURE 3.—Curves of wind direction and speed at Delaware Breakwater, Del., and the temperature record at Cape May, N. J. (roughly 10 miles east) during the passage of the storm, September 15, 1904.

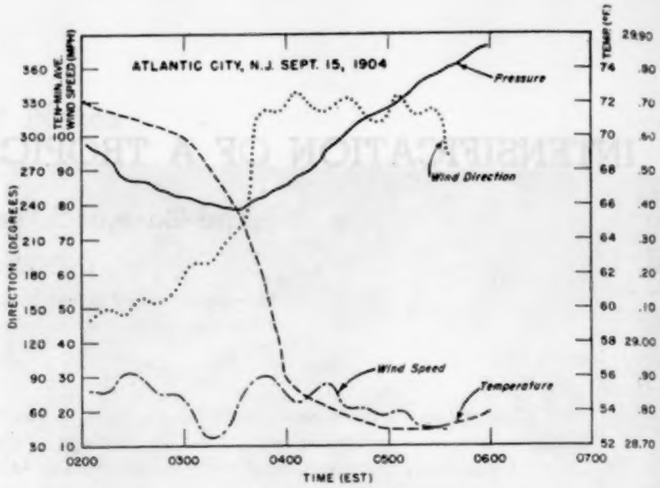


FIGURE 4.—Pressure, temperature, and wind records, Atlantic City, N. J., September 15, 1904.

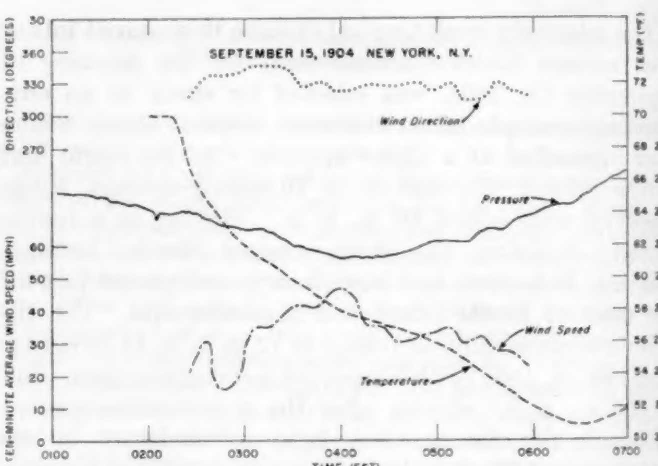


FIGURE 5.—Pressure, temperature, and wind records, New York, N. Y., September 15, 1904.

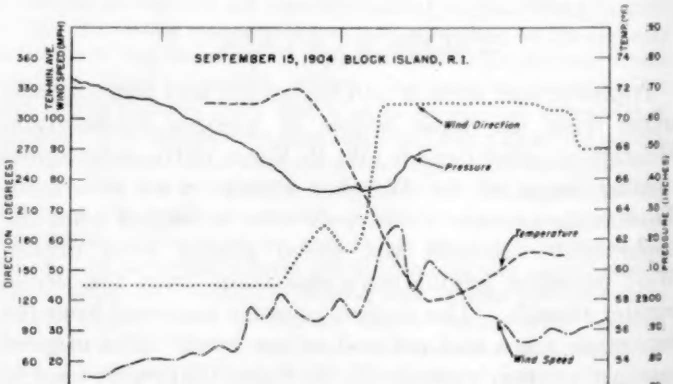


FIGURE 6.—Pressure, temperature, and wind records at Block Island, R. I., September 15, 1904.

to indicate the time the storm was nearest the station. To determine on which side of the station the storm passed, the wind direction was used. The rapidity with which the wind changed direction was used as a measure of the distance of the storm from the station. Barograms of two or more nearby stations were drawn on one chart and the point of intersection of two barograms was used as an indication of the time the storm was an equal distance from the two stations.

After a preliminary track had been constructed using this method, adjustments were made by getting agreement between the position of the storm center on the hourly weather maps and on this preliminary track. Adjustments of the track were also made after preliminary pressure profiles (discussed below) were constructed. In some instances several pressure profiles were made using a different position of a section of the track in each in an effort to find the most reasonable profile.

These methods are very well suited to finding the track of a hurricane which has a well-defined circulation around

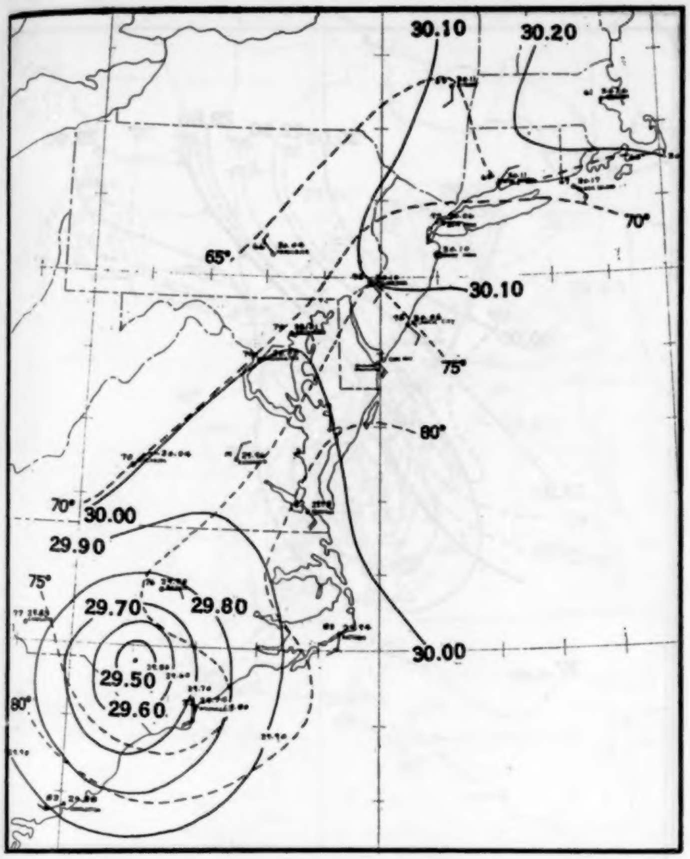


Figure 7.—Surface map, 1300 est, September 14, 1904.

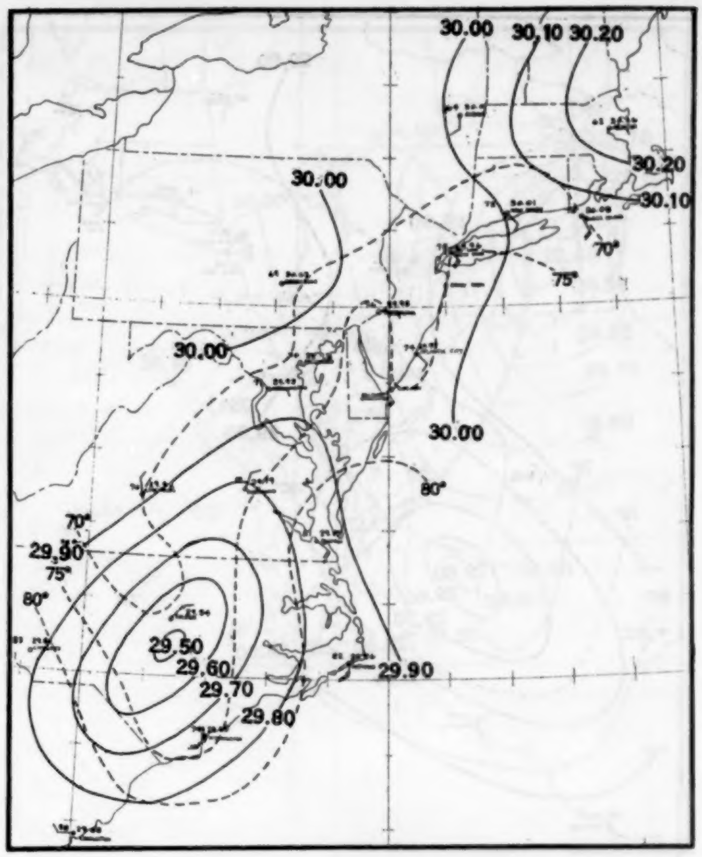


Figure 8.—Surface map, 1600 est, September 14, 1904.

a circular pressure pattern. Since the storm in this study had a circulation that was elongated, the different methods did not always yield the same result. Because of this, in some portions of the track a compromise position was used as the best fit of the track to the weather data.

Pressure profiles (pressure plotted against distance from pressure center) were drawn using hourly pressures from barograms and the distance of the station from the pressure center of the storm at the same time as the pressure reading. A number of stations were used to determine the pressure profile for a given time.

The central pressure p_0 was computed by using the formula [1, 2]

$$\frac{p-p_0}{p_n-p_0}=e^{-R/r}$$

where p_n is the pressure at periphery of storm, R radius of maximum winds, and p pressure at any distance r from storm center. Three equations were used by substituting three different sets of values of p and r obtained from "observed" pressure profiles to solve for the three unknowns, p_0, p_n, and R. This formula was developed for hurricanes in which the pressure field is nearly symmetrical about a point and filling or deepening is negligible over a period of several hours. Although the pressure pattern of the storm in this study was elongated, the calculated value of p_0 is considered reasonable. The value of p_n is not considered very definite. The value of R is not as reliable as the value of p_0 since a small variation in the pressure profile may make a large difference in the value of R.

Hourly surface maps were constructed from thermograms, barograms, and triple-register data. The position of the cold front was determined principally from the thermograph records. The hourly maps were used to help in determining whether the storm was deepening and whether cold air was moving into it, as well as for establishing the storm track. The central pressure was estimated from each hourly map.

The relation of over-water to over-land wind was obtained from [2]. This relationship was used to compare the high wind speed at Delaware Breakwater which had an over-water trajectory with the lower reading across Delaware Bay at Cape May which had an overland trajectory. Adjustment for anemometer height was also used to compare the two wind observations using the method discussed in [2]. The anemometer was 17 feet higher at Delaware Breakwater than at Cape May.

4. RESULTS

The central pressure of the storm decreased as the storm moved north of latitude 36° and then increased after the storm moved north of latitude 39.5°. This is indicated in figure 2, which shows the calculated central

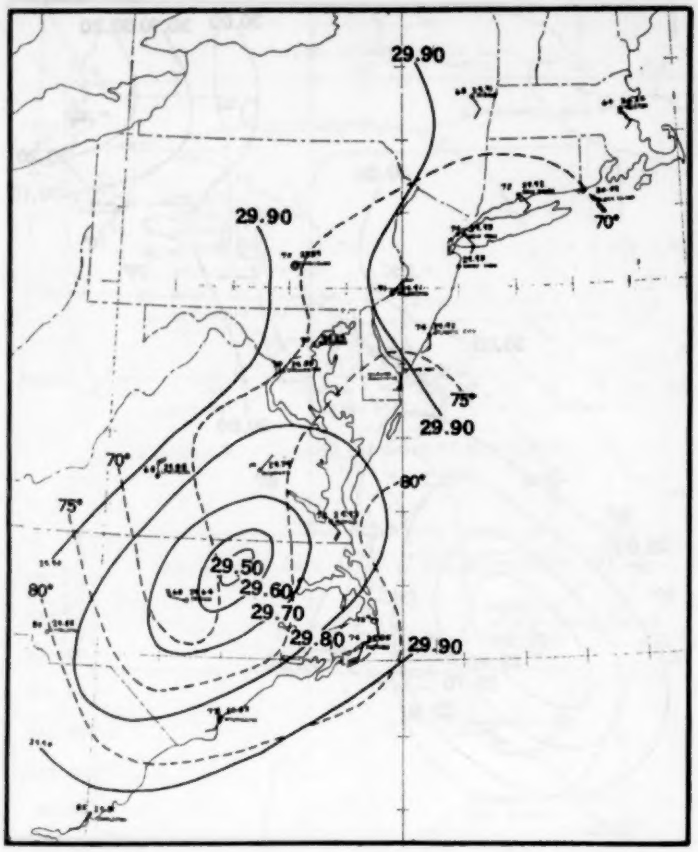


FIGURE 9.—Surface map, 1900 EST, September 14, 1904.

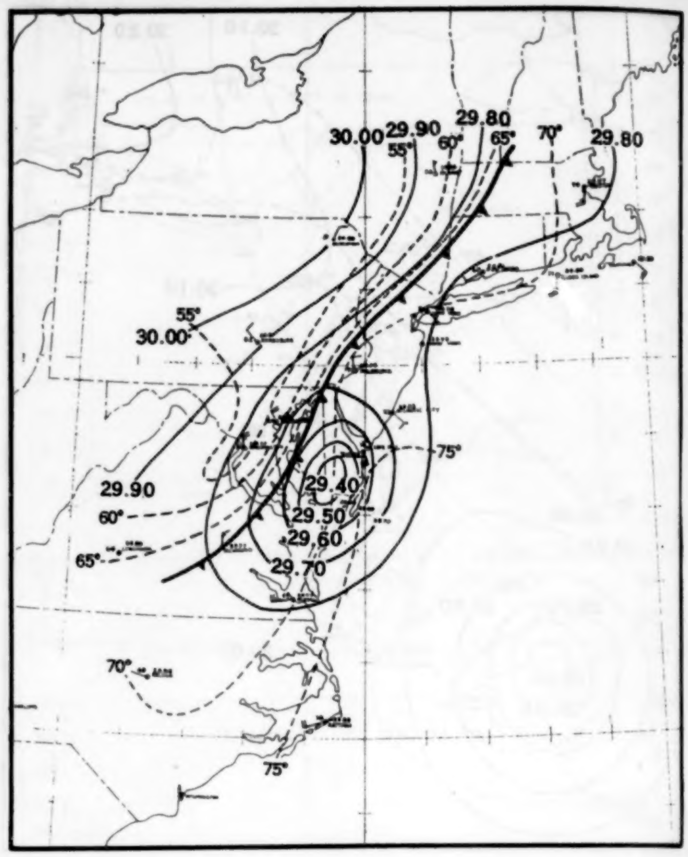


FIGURE 11.—Surface map, 0100 EST, September 15, 1904.

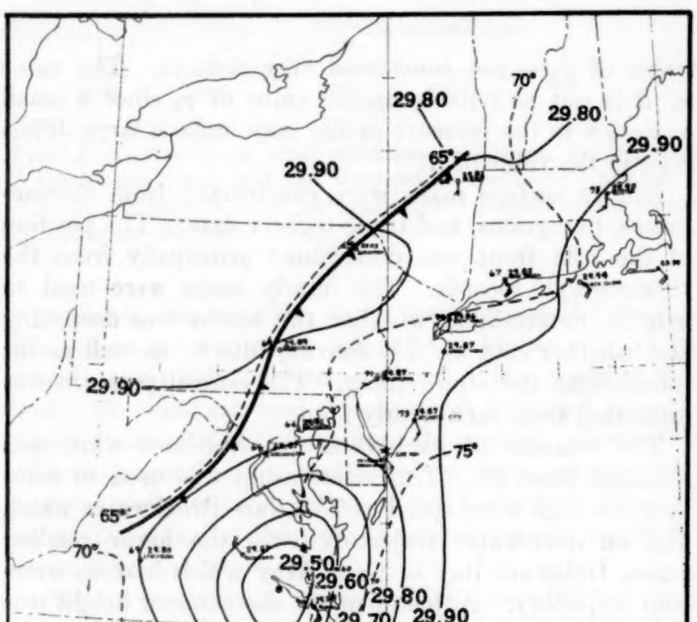


FIGURE 10.—Surface map, 2200 EST, September 14, 1904.

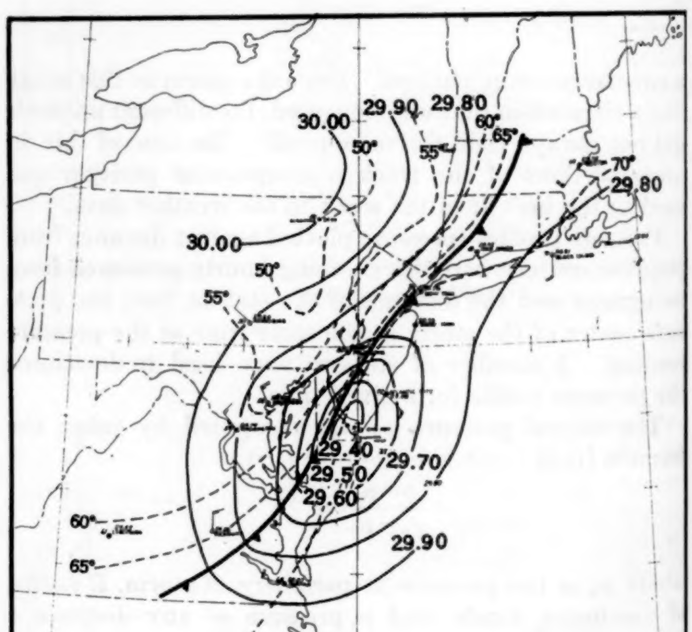


FIGURE 12.—Surface map, 0200 EST, September 15, 1904.

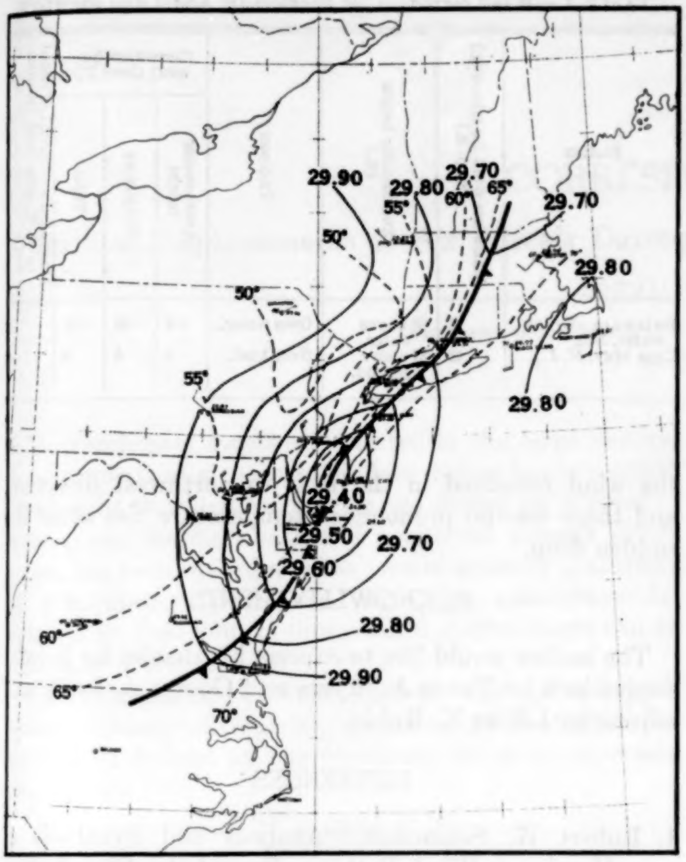


FIGURE 13.—Surface map, 0300 EST, September 15, 1904.

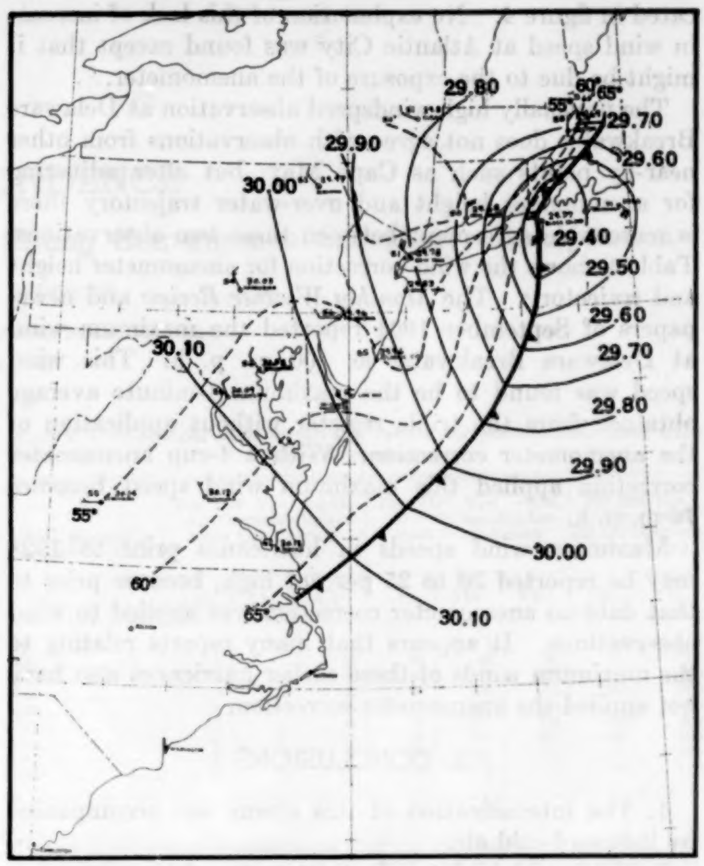


FIGURE 15.—Surface map, 0700 EST, September 15, 1904.

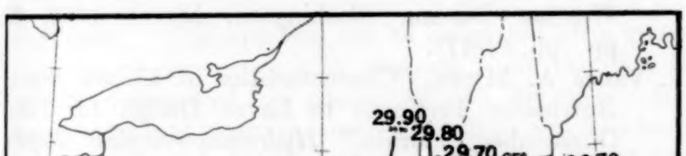


FIGURE 14.—Surface map, 0400 EST, September 15, 1904.

pressure, as well as the estimated central pressure from the hourly maps, and a compromise value for the various times and latitudes.

Cold air moved into the storm as the storm moved northward. This is shown in figures 3–6 which show the barogram and wind direction and speed curves along with the thermogram. Because thermograph and barograph records were not available for Delaware Breakwater, the thermograph from Cape May, N. J., was used with the Delaware Breakwater wind record as shown in figure 3. In this figure, the peak wind shortly precedes the sudden drop in temperature. Delaware Breakwater is roughly 10 miles west of Cape May, which accounts for this difference. Figures 4–6 show that the peak wind occurred after the drop in temperature and at about the time of lowest pressure. Of course, in the case of most cold frontal passages the drop in temperature occurs at about the time of lowest pressure. In this case, however, the lowest pressure was not caused by the frontal passage but by the low pressure of the storm center. This is shown by the surface maps in figures 7–15. The cold front did not move into the storm center and the trough associated with the storm center until 0300 EST of September 15, 1904. After that time the cold front moved along with the storm center.

There was no pronounced increase in wind speed at Atlantic City, N. J., when the cold front passed, as indi-

cated in figure 4. No explanation of this lack of increase in wind speed at Atlantic City was found except that it might be due to the exposure of the anemometer.

The unusually high windspeed observation at Delaware Breakwater does not agree with observations from other near-by points such as Cape May, but after adjusting for anemometer height and over-water trajectory there is reasonable agreement between these two observations. Table 1 shows the wind correction for anemometer height and trajectory. The *Monthly Weather Review* and newspapers of September 1904 reported the maximum wind at Delaware Breakwater as 100 m. p. h. This wind speed was found to be the maximum 1-minute average obtained from the triple register without application of the anemometer correction. With a 4-cup anemometer correction applied this maximum wind speed becomes 76 m. p. h.

Maximum wind speeds in hurricanes prior to 1928 may be reported 20 to 25 percent high, because prior to that date no anemometer correction was applied to wind observations. It appears that many reports relating to the maximum winds of these earlier hurricanes also have not applied the anemometer correction.

5. CONCLUSIONS

1. The intensification of this storm was accompanied by inflow of cold air.
2. Unusually high winds may occur when a storm is moving over land in such a way that the wind has an over-water trajectory.
3. While most storms have the strongest winds in the forward right quadrant, this storm had the strongest winds in the rear left quadrant, associated with the inflow of cold air.
4. The strong winds were not caused by a squall since they persisted for about one hour at Delaware Breakwater; the wind remained in the west to northwest direction, and there was no pronounced temperature rise after the sudden drop.

TABLE 1.—*Wind correction for anemometer height and trajectory*

Station	Maximum wind (10-min.-avg.) (m. p. h.)	Anemometer height (ft.)	Trajectory	Correction (percent) (from [2])			Maximum windspeed adjusted to 51 ft. over land (10-min.-avg.) (m. p. h.)
				Anemometer height	Trajectory	Total	
Delaware Breakwater, Del.	76	68 above water.	Over water..	−3	−28	−31	52
Cape May, N. J.....	42	51 above ground.	Over land...	0	0	0	42

ACKNOWLEDGMENTS

The author would like to express his thanks for helpful suggestions by Vance A. Myers and George A. Lott, and editing by Lillian K. Rubin.

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CORRESPONDENCE

Vertical Displacements of Air Parcels During Strong Convergence and Heavy Precipitation

KENDALL R. PETERSON

Hydrometeorological Section, U. S. Weather Bureau, Washington, D. C.

May 22, 1957

Meteorologists may be interested in the large vertical displacements of air that take place during heavy rainfall. The height to which the parcels rise during an interval of time, given the distribution of horizontal velocity divergence, has been investigated as part of an analytical study of precipitation processes. With the nomogram developed by Peterson [1] this vertical displacement can be related to precipitation.

The relationship between vertical velocity and horizontal velocity divergence, assuming hydrostatic equilibrium, is defined by the continuity equation expressed in the form

$$\frac{\partial \omega}{\partial p} = -\text{Div } \mathbf{V} \tag{1}$$

where $\omega \equiv \frac{dp}{dt}$ is the vertical velocity for a pressure vertical coordinate. This equation can be integrated for a given variation of divergence with pressure. The variation is usually determined by computing the divergence for several constant pressure levels. It will be assumed here that the vertical distribution of divergence during cyclonic activity is a linear one, such that,

$$\text{Div } \mathbf{V} = -(b + cp) \tag{2}$$

where b and c are arbitrary constants that can be evaluated by assuming values of divergence at two levels.

Substitution of equation (2) into equation (1), and integration give

$$\frac{dp}{dt} = a + bp + \frac{1}{2} cp^2 \tag{3}$$

where a is an integration constant that can be evaluated by assuming a value for $\frac{dp}{dt}$ at the surface.

Integration of equation (3) over the time interval Δt gives

$$\left(\frac{cp+b-\sqrt{b^2-2ac}}{cp+b+\sqrt{b^2-2ac}}\right)_f = \left(\frac{cp+b-\sqrt{b^2-2ac}}{cp+b+\sqrt{b^2-2ac}}\right)_i \exp\left(\Delta t\sqrt{b^2-2ac}\right) \tag{4}$$

where the subscripts f and i refer to the final and initial pressure of the air parcel and t is the time required for the parcel to ascend from p_i to p_f. If it is assumed that the level of non-divergence is at 600 mb. and that the vertical velocity at 1000 mb. is zero, equation (4) reduces to

$$\left(\frac{200-p_f}{1000-p_f}\right) = \left(\frac{200-p_i}{1000-p_i}\right) \exp\left(\Delta t \text{ Div } \mathbf{V}_0\right) \tag{5}$$

where Div $\mathbf{V}_0$ is the divergence at 1000 mb.

A graphical solution to equation (5) is given in figure 1. The extreme left scale is the 1000-mb. divergence. Both positive and negative values are included, thereby enabling the use of the nomogram for computation of upward or downward vertical displacement. The horizontal line is the time (Δt) scale. The vertical scales to the right are a reference line (R) (solving the product Δt Div $\mathbf{V}_0$), the final pressure (p_f), and the initial pressure (p_i). Table 1 was prepared from equation (5) and indicates pressure displacements of air parcels at 100-mb. increments.

TABLE 1.—*Vertical displacement of rising air parcels associated with 1000-mb. convergence*

Initial pressure on air parcels (mb.)	For Div V_0= −0.036 hr.$^{-1}$ vertical displacement (mb.) during			For Div V_0= −0.36 hr.$^{-1}$ vertical displacement (mb.) during			For Div V_0= −3.6 hr.$^{-1}$ vertical displacement (mb.) during	
	1 hr.	3 hr.	6 hr.	1 hr.	3 hr.	6 hr.	1 hr.	3 hr.
200	0	0	0	0	0	0	0	0
300	3	9	18	28	63	87	97	100
400	6	15	30	48	119	170	193	200
500	8	20	40	65	163	250	287	300
600	10	20	43	70	198	316	378	400
700	10	19	43	70	211	368	465	500
800	6	17	34	60	194	395	539	600
900	3	9	20	39	137	342	570	700
1000	0	0	0	0	0	0	0	0

TABLE 2.—*Vertical displacement (mb) for one-half inch, one inch, and five inches of precipitation for saturated pseudo-adiabatic atmosphere with various surface dewpoints*

Initial pressure of air parcel (mb)	Surface dewpoint								
	40° F			60° F			75° F		
	0.5 in.	1 in.	5 in.	0.5 in.	1 in.	5 in.	0.5 in.	1 in.	5 in.
200	0	0	0	0	0	0	0	0	0
300	85	98	100	59	84	100	46	72	100
400	166	196	200	112	164	200	83	137	200
500	241	292	300	154	237	300	112	193	299
600	305	387	400	183	300	400	129	237	399
700	349	479	500	193	346	500	131	261	498
800	362	562	600	177	360	600	115	252	597
900	310	616	700	121	299	699	73	185	693
1000	0	0	0	0	0	0	0	0	0

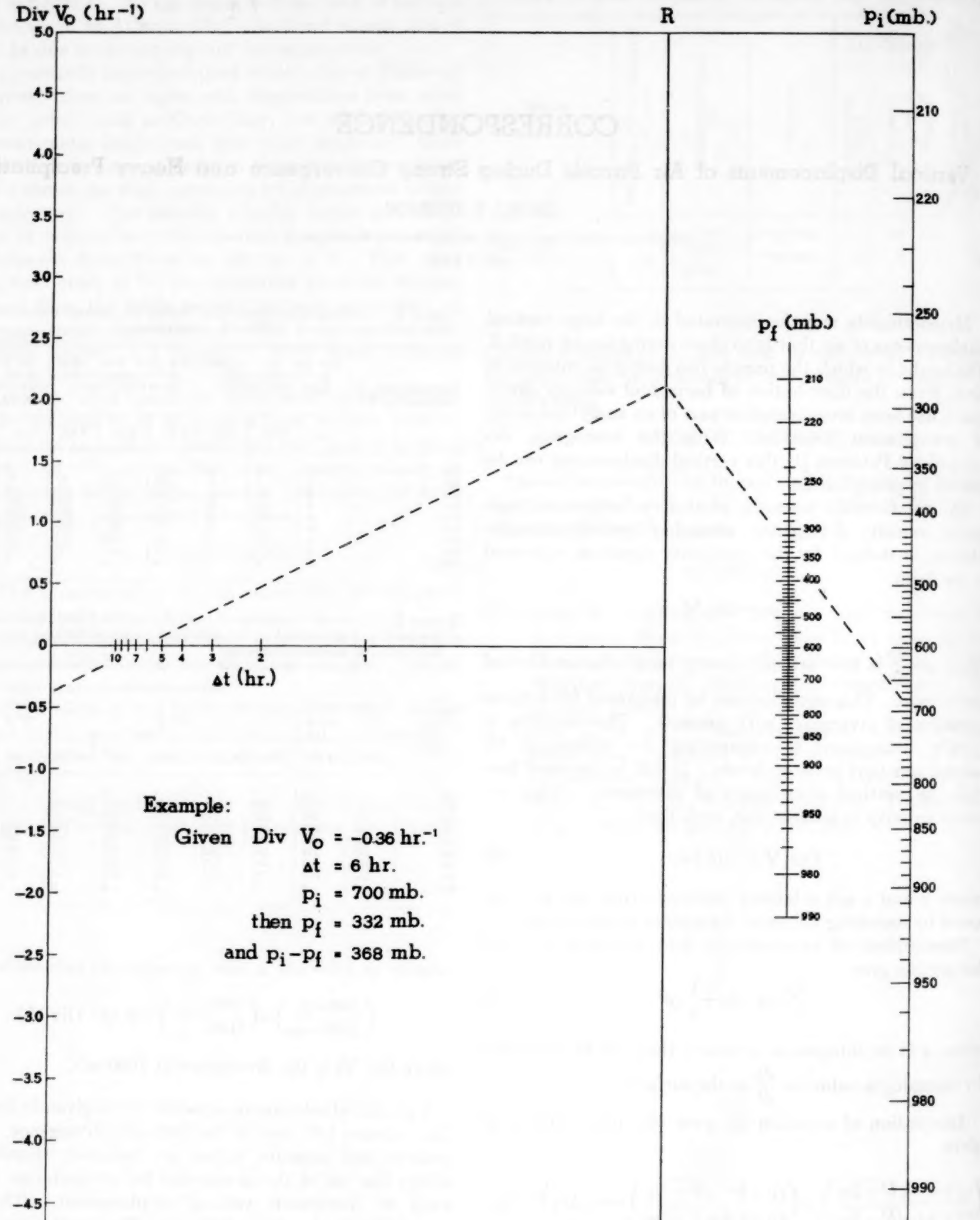

FIGURE 1.—Nomogram for computing vertical displacement (final pressure p_f) as a function of initial pressure (p_i), horizontal divergence at 1000 mb. (Div V_0), and time (Δt). The nomogram is based on the assumption of linear change of horizontal divergence with pressure, with zero divergence at 600 mb.

Under the assumptions made here and in the previous paper [1] (all of which seem realistic), the vertical displacement is related directly to the precipitation that falls from a column and to the moisture conditions in the column (regardless of the time during which the precipitation occurs). Table 2, computed from these assumptions, gives typical values of vertical pressure displacement for rainfall amounts of 0.5 inch, 1.0 inch and 5 inches.

The writer wishes to thank Dr. C. S. Gilman for suggesting the idea which is an elaboration of pages 57–61 of reference [2].

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Weather Notes

(Continued from page 272)

versity of California at Los Angeles (Weather Bureau Contract CWB 7904), June 1950; see Part I, p. 16). These parallel bands with associated bright spots may offer good opportunity for estimating cloud movements as the bands appear to be a fairly permanent feature of the cloud mass. Unfortunately, no theodolite readings were taken on these parallel bands.

At the time the clouds were first observed, none of the forecasters or observers on duty had ever seen noctilucent clouds (Mr. Glommen came on duty at 0100 AST). Since the clouds were on the north-northeastern horizon near the sun's rays at this time of year, a few people believed them to be very high cirrus such as have been reported by jet aircraft pilots at altitudes above 40,000 or 45,000 ft. However, after identifying cirrus clouds the following day and observing the behavior of the sunlight on these clouds after sunset, no doubt remained that the clouds observed the previous night were at vastly higher elevations than normal cirrus clouds. The cirrus clouds observed on Sunday night were entirely dark by 2300 AST. The noctilucent clouds seen Saturday night were definitely in the sun's rays and had no significant color changes from the time they were first observed until they disappeared near sunrise. A faint orange glow caused by smoke or haze persisted in the northern sky through the night.—*W. B. Lindley, Meteorologist in Charge, WBAS, Anchorage, Alaska.*

TEMPERATURE AND WIND FIELDS AT THE TIME OF NOCTILUCENT CLOUDS IN ALASKA, JULY 27–28, 1957

Most noctilucent clouds are observed at elevations of 65 to 90 km. in the vicinity of the mesopause between ozonosphere and ionosphere. Although these clouds occur well above the highest layers from which radiosonde data are obtained, an examination of constant pressure charts was made.

The wind flow at 50 and 25 mb. over southern Alaska from 24 hours before to 24 hours after the observation of noctilucent clouds described in Mr. Lindley's note was generally easterly, 5–10 knots. Winds and height changes indicate that a weak trough moved across the area from west to east during the period. At 500 mb., a stronger trough in the westerly winds simultaneously moved in the same direction, suggesting that the trough effect was impressed from below the 50-mb. level.

The temperature field was very weak and typical of that month. Temperatures at both 50 and 25 mb. were warmer to the north so that the easterly winds increased upward through the layer and also for some distance above the 25-mb. level.

At sea level and 500 mb. a weak residual Low moved into the sea area south of Anchorage with little wind flow over the mountain ranges.

A possible explanation of the noctilucent clouds can be found in the apparent general convergence in the vicinity of the trough in a deep layer extending above the 50-mb. level. This is suggested by temperature decreases of one or two degrees at 50 mb. and of about one degree at 25 mb. during a period when cold air advection was not indicated by the streamline-isotherm pattern.

In summation, there is only a slight and inconclusive indication of conditions at 50 and 25 mb. that might explain an unusual event such as noctilucent clouds at a height of possibly 80 km.—*S. Teweles, U. S. Weather Bureau, Washington, D. C.*

RARE WATERSPOUTS IN ALASKA

On August 19, 1957 between 0900 and 1045 PST, two distinct waterspouts were observed in Cross Sound, 20 miles southwest of Cape Spencer Light Station, Alaska. These were sighted by Goody Winthrop, a deep-sea fisherman. During this period, he also observed several other waterspouts in the process of forming. These were observed to start downward from a cloud formation which he estimated to be 1,000 feet high.

On that day Cape Spencer reported an estimated 1,500-foot overcast, visibility 15 miles, temperature 51° F., dewpoint 49° F., and the wind east-southeast at 12 knots. The synoptic situation showed a cold trough over the eastern Gulf of Alaska with a cold cut-off Low over the southeastern gulf. The nearest raob report, taken at Yakutat, 150 miles northwest of Cross Sound, at 0400 PST showed moist unstable air from the 900-mb. level to 600 mb. with an isothermal layer from the surface to 900 mb. The average lapse rate slightly exceeded 4° F. per 1,000 feet and the degree of instability for that stratum was about −1.6° C. (difference between temperature of air parcel after being lifted from 900 to 600 mb. and the observed 600-mb. temperature). Heavy rain showers were reported throughout the area by pilots, and lightning was also reported in Juneau the previous night, which lends support to the statement that the air was unstable.

Another interesting fact was the abnormally high sea temperatures in the eastern part of the gulf. The FWS Research Vessel *Cobb* measured sea temperatures of 64° F. between Cape Ommaney and Cape St. Elias during that period on the 19th although in the Cross Sound area itself the reading was 54° F. It could not be ascertained for sure whether or not the waterspouts appeared where the sea temperatures were abnormally high.—*Gordon D. Kilday, WBAS, Juneau, Alaska.*

THE WEATHER AND CIRCULATION OF AUGUST 1957 [1]

RAYMOND A. GREEN

Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.

1. JULY-AUGUST PERSISTENCE

The summers of 1957 and 1956 were similar in that a sharp circulation reversal from June to July was followed by marked persistence from July to August at middle latitudes of the Western Hemisphere [1]. A high correlation was found between 700-mb. height anomalies of the latter pair of months for both years, as shown by the first line of table 1. In the area from 30° to 50° N. and 70° to 130° W. the correlation coefficients for both 1956 and 1957 far exceeded the .33 figure found by Namias [2] for the years 1942–1950.

Temperature anomalies over the United States in 1957 did not exhibit as great a degree of persistence as did 700-mb. height, principally because of the influence of high-latitude circulation changes (fig. 1). Cooling was extensive from July to August, lowering the temperature anomalies by one or more classes at 63 of 100 representative stations. Precipitation amounts were slightly less sensitive to remote circulation influences, changing class at only 57 of the 100 stations (table 1).

2. GENERAL CIRCULATION

Despite high July-August persistence in middle latitudes, several large 700-mb. height changes occurred at high latitudes. Figure 1 shows anomalous height falls of 300 ft. in the Arctic Basin, where an already intense July polar vortex [3] deepened to a remarkable mean value of 420 ft. below normal during August (fig. 2). Strong westerly winds (fig. 3) helped maintain a nearly complete circumpolar band of above normal 700-mb. heights south of the polar vortex, but with centers of action considerably displaced from July positions. Blocking in the Bering Sea and the Greenland-Iceland area was wiped out by falls in excess of 300 and 200 ft., respectively (fig. 1). Two changes of more than 300 ft. reversed the Canadian circulation pattern and produced an impressive couplet consisting of a blocking High in the Yukon and a strong Low in Hudson Strait (fig. 2).

A tendency toward high-latitude blocking over Siberia and western Canada was associated with southward displacement of the 700-mb. westerlies. Figure 3 illustrates the extent of this suppression since the 700-mb. mean jet stream (solid) was observed along or north of its normal August track (dashed) in only a small portion of the

[1] See Charts I-XVII following p. 296 for analyzed climatological data for the month.

TABLE 1.—*Persistence measures of monthly mean anomalies in the United States from July to August*

	1956	1957	1942-50
700-mb. height (lag correlation)	0.76	0.80	0.33
Temperature (0 or 1 class change, percent)	85	78	82
Precipitation (0 class change, percent)	43	43	34

Northern Hemisphere (central Pacific and from James Bay to the British Isles).

In general, the mid-latitude circulation of the Western Hemisphere was typical of August, featuring mean troughs in the west-central Pacific and along both coasts of the United States and mean ridges in the eastern Pacific, continental United States, and central Atlantic. Only two of these systems were significantly stronger than normal; i. e., the east coast trough and the Atlantic ridge. Monthly mean 200-mb. systems (fig. 4) were essentially superimposed on their 700-mb. counterparts, except that the 200-mb. west wind maximum was somewhat farther to the south in the east coast trough (compare solid jet axes in figs. 3 and 4).

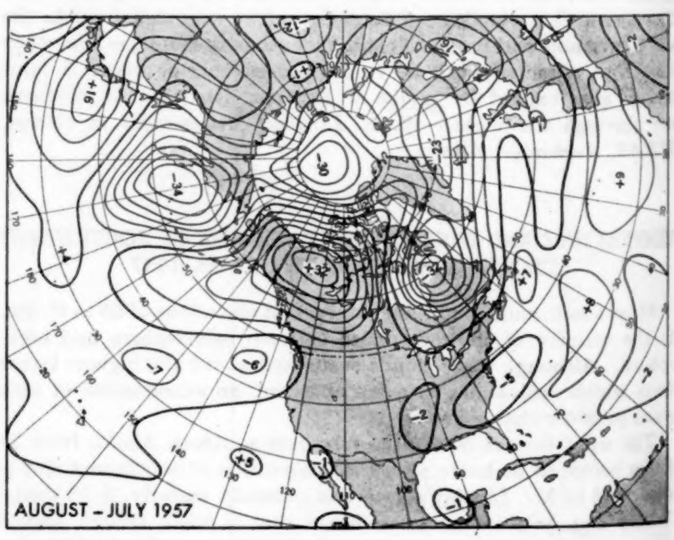

FIGURE 1.—Changes in monthly mean 700-mb. height departures from normal from July to August 1957. The lines of equal anomalous height change are drawn at 50-ft. intervals with the zero line heavier and the centers labeled in tens of feet. Large changes occurred in the polar regions, the Bering Sea, northwestern Canada, eastern Canada, and near Iceland. Small changes were predominant over the United States.

For the most part the location of the coastal troughs on 5-day mean maps during the month varied little from their mean monthly positions. A noteworthy exception was the temporary retrogression of the east coast trough which played a large part in late-month drought relief.

3. CIRCULATION AND UNITED STATES TEMPERATURE ANOMALIES

This month offers an interesting example of the way United States temperature anomalies are often affected by circulation features some distance away. Temperature anomalies in July and August 1957 may be compared in figure 5 for differences shown in table 1.

Cooling from the Great Lakes eastward can be associated with the effects of northerly DN flow on the monthly mean map (fig. 2), as described in a number of articles in this series (especially Hawkins [4]). Farther west the relation between cooling and circulation was less straightforward, since monthly mean 700-mb. heights continued above normal in the Northern Plains. However, figure 1 shows that large height rises in northwestern Canada combined with pronounced falls in eastern Canada to

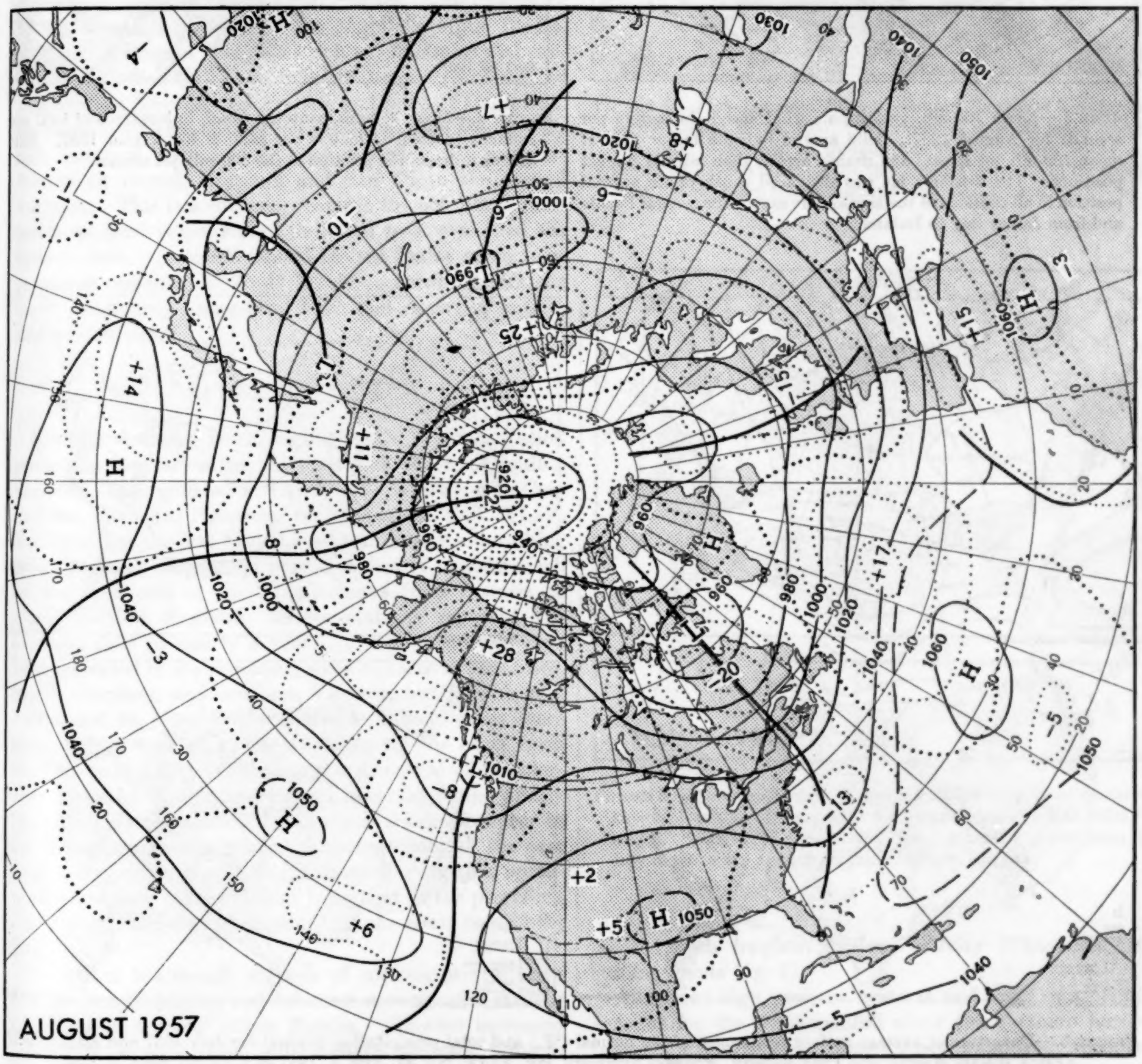

FIGURE 2.—Mean 700-mb. contours (solid) and height departures from monthly normal (dotted), both in tens of feet with troughs indicated by heavy lines, for August 1957. Important features include a blocking High over northwestern Canada, a warm High over Texas, and a deeper than normal mean trough in eastern North America.

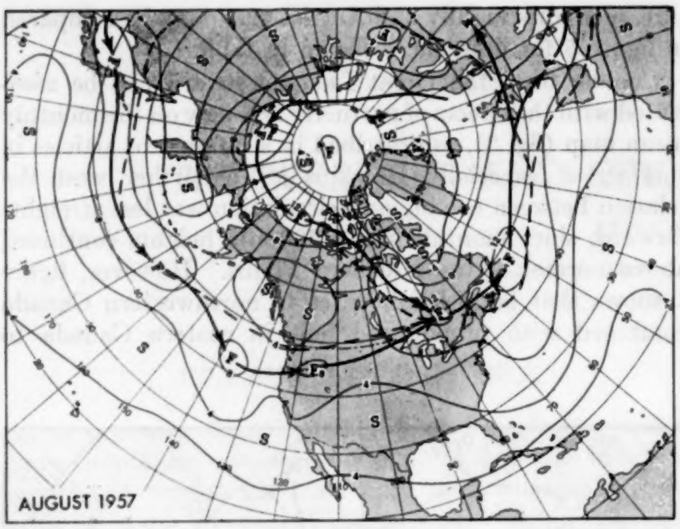

FIGURE 3.—Mean 700-mb. geostrophic wind speed (in meters per second) for August 1957. Solid arrows indicate major axes of mean 700-mb. jet stream and dashed arrows their normal August positions. The westerly jet was displaced south of its normal position in all portions of the hemisphere except the central Pacific and from James Bay to Ireland.

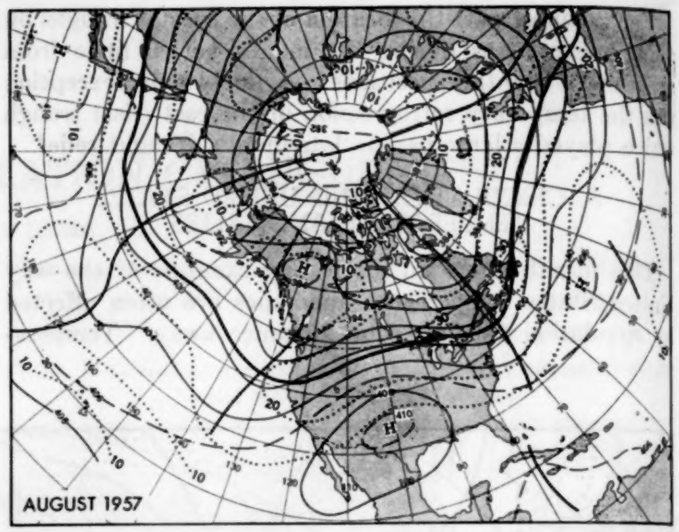

FIGURE 4.—Mean 200-mb. contours (solid, in hundreds of feet) and isotachs (dotted, in meters per second) for August 1957. Solid arrows indicate the position of the 200-mb. jet stream.

FIGURE 5.—Departure of average surface temperature from normal (°F.) and total precipitation (inches) for July 1957 and August 1957. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLIV, No. 31, Aug. 5, 1957 and No. 35, Sept. 2, 1957.)

produce increased northerly flow components throughout central Canada. As a result cool polar air masses were transported across the northern border of the United States producing low temperatures in the northern Great Plains. One mechanism by which much of the cooling was accomplished is represented on Chart IX, giving the tracks of centers of anticyclones at sea level. A cool polar anticyclone moved into the Northern Plains of the United States from northwestern Canada early in the month, and others from southwestern Canada followed later, lowering temperatures from the Northern Plains across the Great Lakes to the Middle Atlantic States.

Cloudiness and precipitation accompanying migratory cyclones (Chart X) had a cooling effect in the Northern Plains, the Gulf States, and the Middle Atlantic States. Some infiltration of cool air as well as cloudiness and precipitation under the western moist tongue combined to cool western Nevada and Arizona and most of California. Southern California coastal temperatures were abnormally high however, with Los Angeles reporting the warmest August on record, Burbank and San Diego the second warmest. This is a common reaction to cool inland temperatures, and is generally attributed to a weakened sea breeze effect. In south-central United States mean temperatures remained 1° to 4° F. above normal under the nearly stationary upper-level High and generally anticyclonic circulation.

4. PRECIPITATION

Eastern drought relief highlighted the precipitation picture in August, occurring mostly in the week ending the 26th. As reported in the *Weekly Weather and Crop Bulletin, National Summary* for that week (vol. XLIV, No. 34): "For the first time this season, steady soil-soaking rains, yielding about 1 to over 5 inches of moisture, fell on the area east of the Appalachians from Georgia to southern New England. Some stations reported the heaviest falls in nearly a year. . . ." Some relief had been provided in the preceding week in eastern Tennessee, North Carolina, and southern Virginia, but for the area northward to New England the first good rains were produced by a small storm travelling up the coast from the 25th to the 27th. This storm is discussed in considerable detail by Kibler and Rogers in an adjoining article [5]. The effectiveness of the storm as a rain-producer in the drought area was related to retrogression of the east coast 5-day mean trough (fig. 6) contributing to a northward trajectory quite different from that of the preceding wave which had moved eastward off the coast (see Chart X).

Earlier in the month an area of copious precipitation over eastern Oklahoma and Arkansas accompanied stalling remnants of tropical storm Bertha. Showers increased rainfall in a zone from southwestern Arizona through central Utah, a westward shift from July (cf. fig. 5b and 5d). In northern portions of the Rocky Mountain States, Great Plains, and Mississippi Valley, precipitation increased with frequent cyclone activity (Chart X) and stalling fronts (fig. 7).

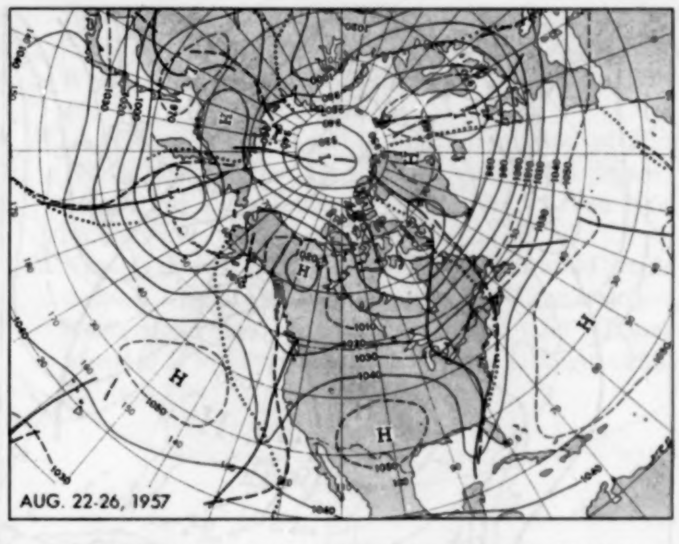

Figure 6.—Five-day mean 700-mb. contours (in tens of feet) for the period August 22–26, 1957. Solid vertical lines are mean trough positions. Positions of troughs for period August 20–24 are shown by dashed lines and for the period August 17–21 by dotted lines. Note sharp retrogression of east coast trough.

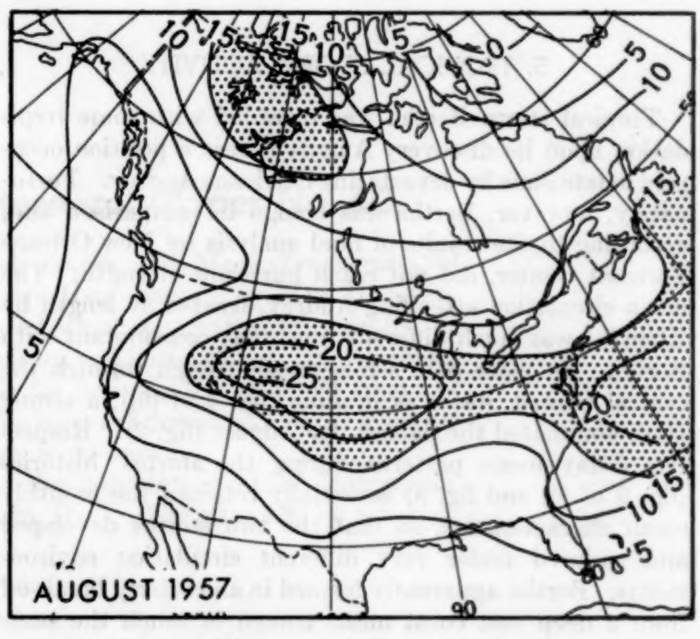

Figure 7.—Number of days in August 1957 with surface fronts of any type within squares with sides approximately 500 miles in length. Temperature anomalies were generally lower than in July north of the zone of maximum frontal activity.

Abundant high pressure systems and few Lows helped account for the scant rainfall along the northern border from the western Great Lakes eastward and from Missouri through southern Illinois, Indiana, Ohio, and Pennsylvania. Dry weather continued in the Southern Plains near the center of the upper-level continental anticyclone.

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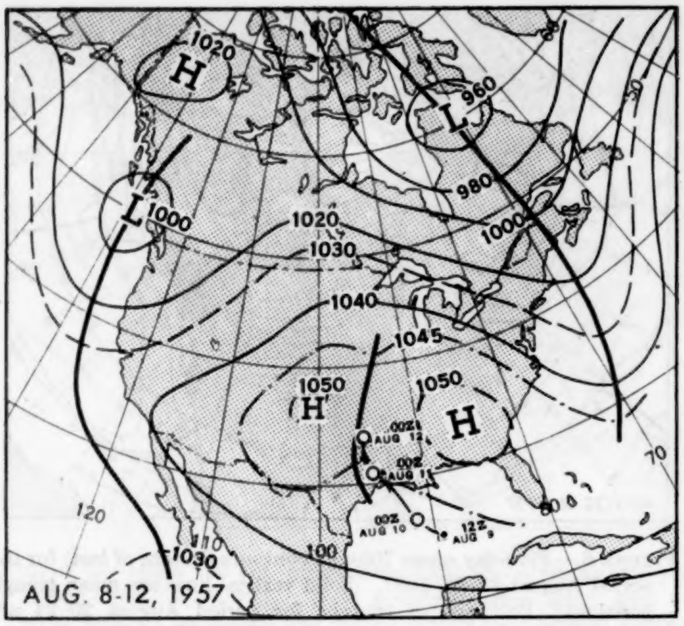

FIGURE 8.—Five-day mean 700-mb. map (in tens of feet) for the period August 8–12, 1957. Track of tropical storm Bertha is shown by arrows.

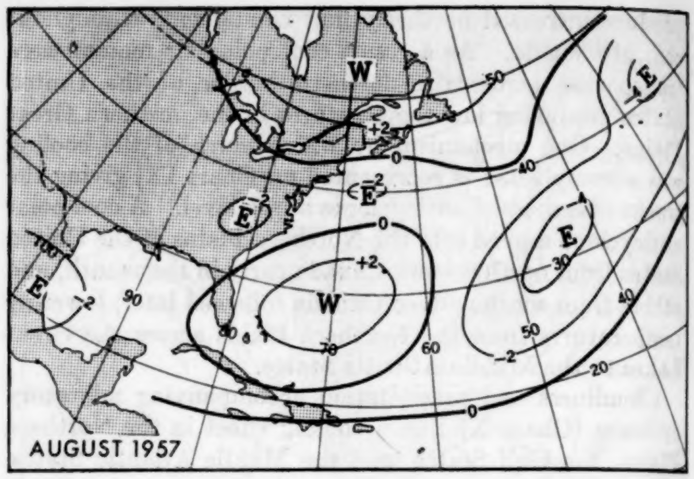

FIGURE 9.—Departure from normal of zonal wind speed component on monthly mean 700-mb. map for August 1957 (in meters per second). A large area of stronger than normal westerlies is shown off the south Atlantic coast.

5. TROPICAL STORM ACTIVITY

Tropical storm Bertha was regarded with some trepidation upon its discovery August 8 near a position occupied in late June by devastating hurricane Audrey. Fortunately, however, Bertha was benign in comparison and, according to the results of final analysis by New Orleans Forecast Center, did not reach hurricane strength. The mean circulation attending Audrey, treated at length by Klein [6], was much different from that concomitant with Bertha. In place of a strong mean trough through the central United States as in June (fig. 4 of [6]), a strong High dominated the pattern for August (fig. 2). Respective 5-day mean patterns during the storms' histories (fig. 9 of [6] and fig. 8) essentially retained the monthly mean characteristics, so that the two storms developed and endured under very different circulation environments. Bertha apparently formed in an easterly break-off from a deep east coast mean trough in much the same manner as the small tropical storm of June 1956 [7].

A zonally-oriented ridge was located north of Bertha's path (fig. 8) subsequent to its formation, in sharp contrast to the deep mean trough along the path of Audrey [6]. The bridge of high pressure north of Bertha effectively shortened the storm's life and at the same time blocked almost all motion in the last few days of its deterioration over Arkansas. An interesting aspect of this stalling was the associated rain area, with higher totals (up to 8 inches) than any observed along the path of Audrey at similar latitudes. Audrey's absorption into a polar trough in the Mississippi Valley, however, did produce a storm with larger amounts of rain in Illinois and Indiana.

Climatology favors formation of about one tropical storm in the Atlantic Ocean during August. None were reported this month, however, even though sea surface temperatures (not shown) were sufficiently warm (over 81° F.) over the areas where most have formed in the past 70 years. While the northerly position of the major 700-mb. jet axis over eastern North America and the Atlantic (fig. 3) would not inhibit the formation of tropical storms [8], the presence of mean westerlies near the generating area might be expected to have an adverse effect. Figure 9 brings into focus the secondary area of higher than normal westerly wind speeds off the south Atlantic coast at the 700-mb. level, while figure 4 shows that westerly winds prevailed at the 200-mb. level in the eastern Atlantic between 15° and 30° N.

In the Pacific, tropical storms were more numerous, with three reported between Hawaii and Mexico early in the month (Chart X). Later in the month, at least one storm formed in the central Pacific and two reached typhoon proportions in the western Pacific. Typhoon Alice appeared around mid-month, moving northward across Korea, while Bess reached typhoon intensity some 2 weeks later.

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U. S. Weather Bureau Research Paper No. 40

Research Paper No. 40, "Principal Tracks and Mean Frequencies of Cyclones and Anticyclones in the Northern Hemisphere," by Wm. H. Klein, was recently issued. Charts are presented which summarize by months the frequency of and regions of genesis of cyclones and anticyclones. These charts and previous studies are used as a basis for deriving the principal tracks of cyclones and anticyclones. Additional statistics are presented and the synoptic climatology of cyclones and anticyclones is discussed.

This publication is available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. The price is $1.00 per copy.

DROUGHT RELIEVING RAINS FOR ATLANTIC COASTAL STATES, AUGUST 23-26, 1957

CLARENCE L. KIBLER AND MARVIN R. ROGERS

National Weather Analysis Center, U. S. Weather Bureau, Washington, D. C.

1. INTRODUCTION

The summer months of 1957 have been among the driest on record at many eastern United States stations. Atlantic City, N. J., Philadelphia, Pa., Washington, D. C., Greenville, S. C., and Chattanooga, Tenn., all experienced the driest July on record [1]. Rainfall deficiency persisted through much of August with sporadic showers giving only temporary relief to small areas.

The serious nature of the drought is illustrated by this comment from the *Weekly Weather and Crop Bulletin, National Summary*, for the week ending August 19, 1957 [1]: "Prolonged drought tightened its grip over most of [the] area [Maryland and Delaware] during the week. . . . Field and sweet corn in the two-State region and about one-half of [the] southern Maryland tobacco crop [were] too far advanced to be benefited [from subsequent rain]."

This article will examine the events leading up to frontal wave development along the Carolina coast and the subsequent rainfall in amounts large and general enough to relieve the drought of the Atlantic Coastal Plain States.

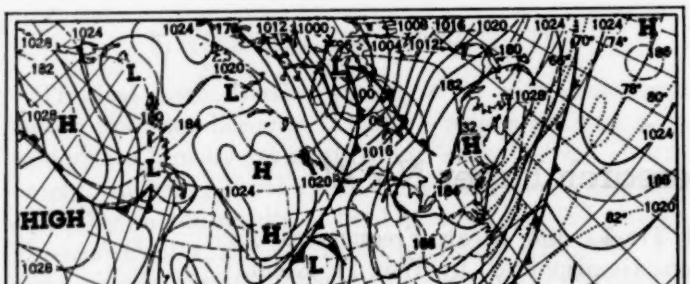

FIGURE 1.—Synoptic patterns for 0000 GMT, August 23, 1957. (A) Surface isobars (solid lines) with fronts, and 1000-500-mb. thickness lines (dashed). Stippled area shows current precipitation pertinent to this study. Dotted lines along east coast are mean sea surface isotherms. (B) 500-mb. chart with height contours (solid lines) and isotherms (dashed lines).

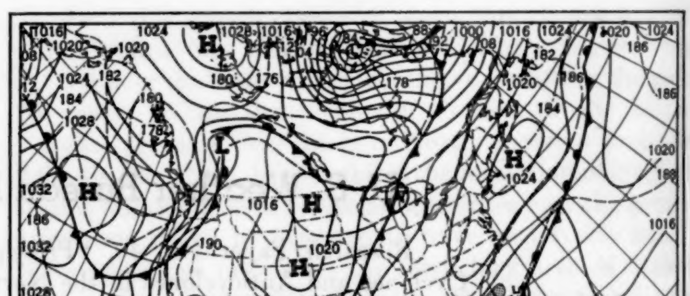

FIGURE 2.—Synoptic patterns for 0000 GMT, August 24, 1957.

2. ANTECEDENT CONDITIONS

The long-wave pattern of the 500-mb. level at 35° N. during much of the summer of 1957 was so organized as to maintain troughs near 75° W. and 130° W. with a ridge near 90° W. North of 45° N. the pattern was more changeable. As the storms' centers passed through Canada, the associated fronts affected the northern tier of States and little impression was made on the pattern over the South and Southeast. See article by Green [2] elsewhere in this issue for more comprehensive discussion of the month's weather.

During mid-August, a cold front of moderate intensity passed off the east coast, the cold air penetrated deep into the southeastern States, and completely dominated the entire area east of the Mississippi River (fig. 1A). Subsequent wave development on the front near Charleston, S. C., brought the relief from drought conditions.

3. SYNOPTIC ASPECTS

The passage of the cold front along the east coast was followed by the season's first large (1034 mb.) "cold" High, pictured in figure 1A, 0000 GMT, August 23. The 500-mb. chart for the same time (fig. 1B) illustrates the upper-air picture prior to frontal wave development. The main features were cold troughs along the east coast and just off the west coast with a less evident long-wave ridge between them. The trough along the western border of the Dakotas became increasingly important as it moved through the long-wave ridge in central United States. The small amplitude of this trough is characteristic of short-wave troughs as they move through long-wave ridge positions with their significance frequently being masked until they emerge east of the major ridge position. A good indicator of the trough's potential was shown in the 12-hour 500-mb. height fall pattern that preceded it and which brought a complete collapse, with time, of the ridge extending into northeastern United States. A deepening Low at 500 mb. over Hudson Bay was associated with surface development in that same area.

By 0000 GMT, August 24 (fig. 2A), there was evidence of squally weather and a tightening pressure gradient in the area east of Jacksonville, Fla. A closed low circulation was analyzed on the surface chart. The easterly wave shown in figure 1A merged with the frontal trough, and, perhaps, aided in the surface development. At 500 mb. (fig. 2B), the ridge over Pennsylvania had become quite narrow. The resultant flows favored the east-southeastward advection of both the cold air and vorticity in the Great Lakes trough. In view of this expected pattern, development was forecast by NAWAC, working from 0600 GMT, August 24 data, to occur on the east coast frontal system. The intensity of this development was correctly forecast, but it was positioned too far east.

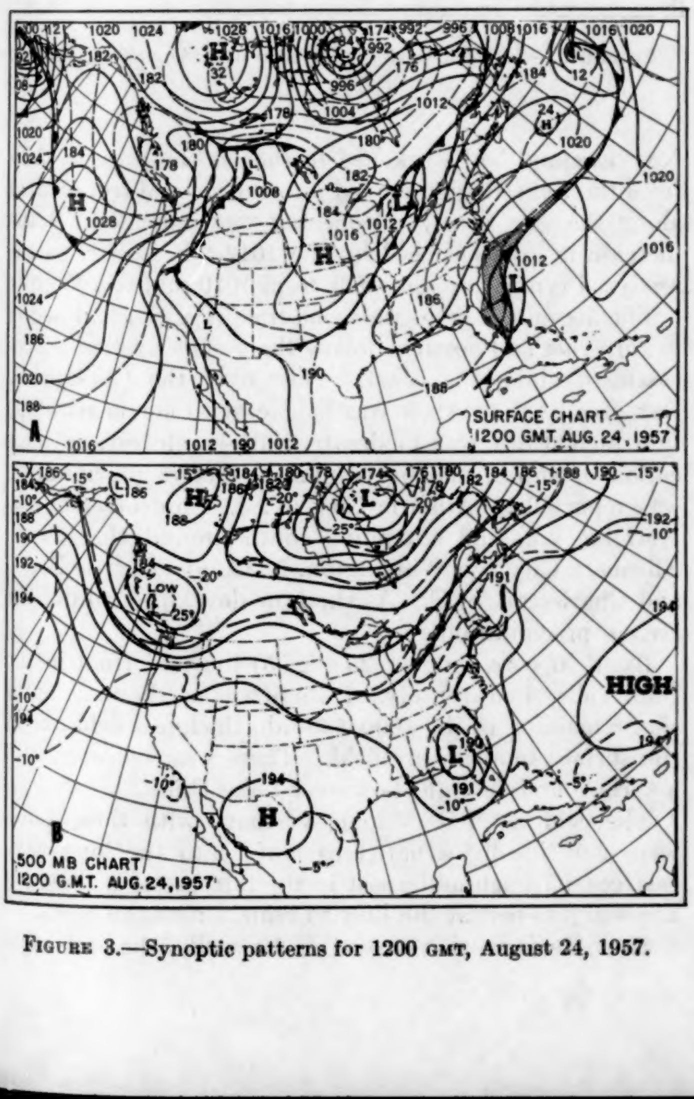

Figure 3.—Synoptic patterns for 1200 GMT, August 24, 1957.

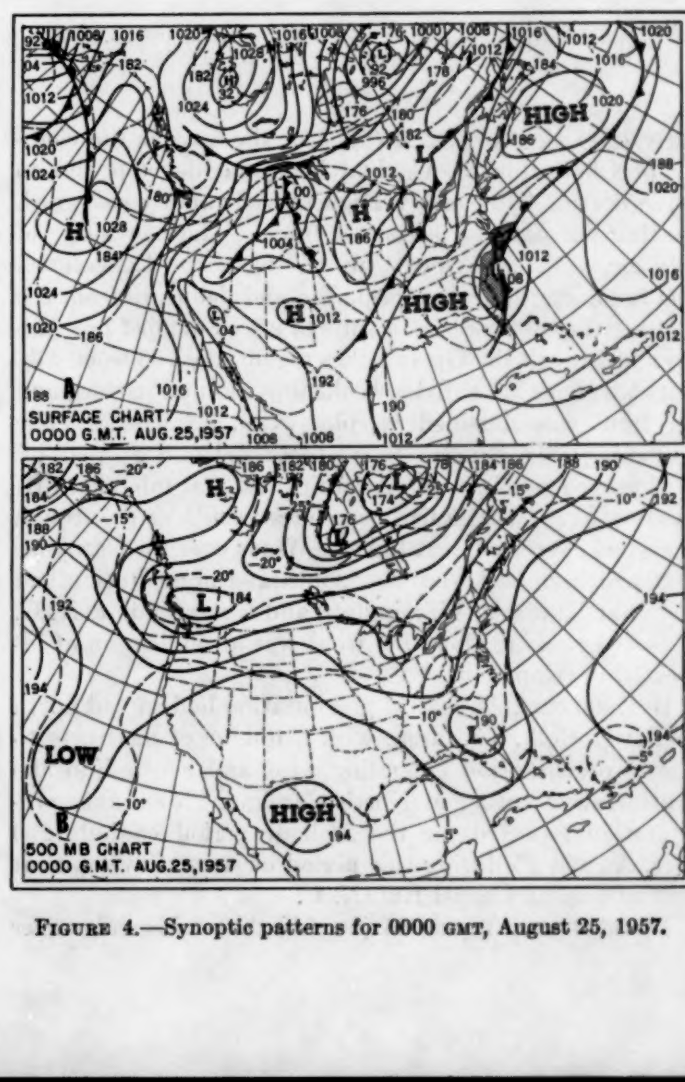

Figure 4.—Synoptic patterns for 0000 GMT, August 25, 1957.

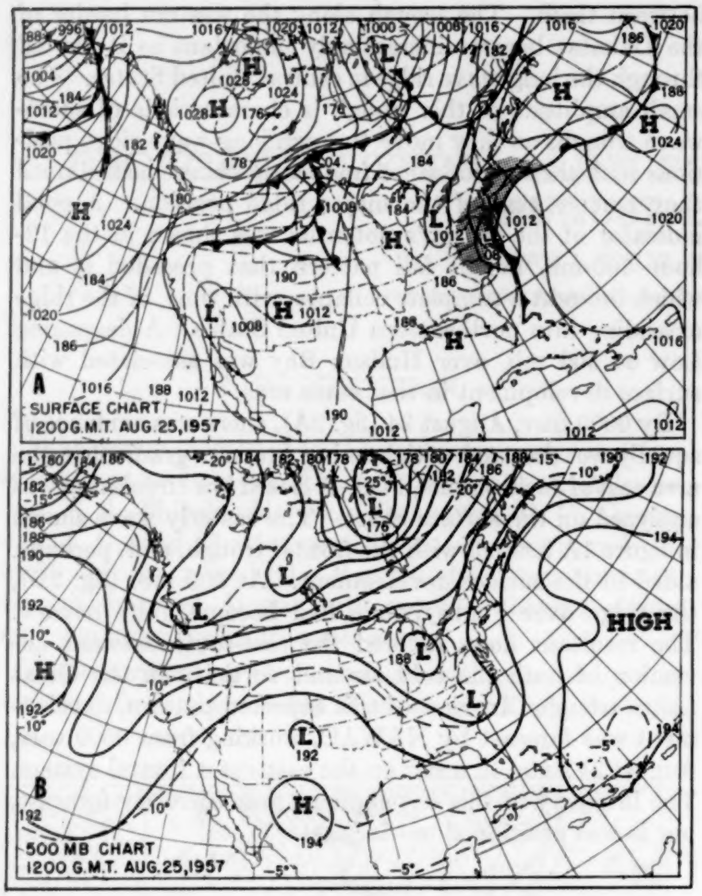

Figure 5.—Synoptic patterns for 1200 GMT, August 25, 1957.

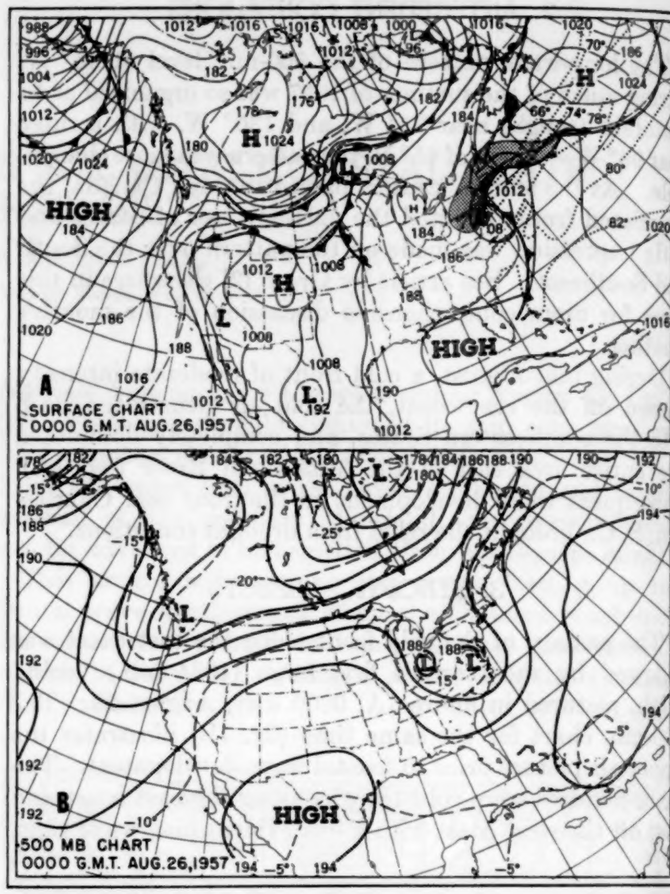

Figure 6.—Synoptic patterns for 0000 GMT, August 26, 1957.

By 1200 GMT, August 24 (fig. 3A), the wave in the vicinity of Charleston, S. C., had begun to develop and to move north. The surface High moved rapidly eastward, opening the path for a coastal track. The new surge of cold air, with cold front through the Great Lakes area, was becoming difficult to separate and delineate from the air over the east coast. In spite of a well defined pressure trough through the Great Lakes region, the 1000–500-mb. thickness lines indicated a weakening thermal pattern and the front was classified as cold, weak, decreasing. The deepening over Hudson Bay had ceased and a break-off Low moved out into the Atlantic. At 500 mb. (fig. 3B) the Low over Georgia had been forced south as the trough deepened over the Great Lakes. Winds over the Carolinas that had been east were now south and precipitation had begun at Hatteras, Wilmington, and Cherry Point, N. C. This overrunning along the front was an indication of increased development.

By 1800 GMT, August 24 precipitation had spread north to the Norfolk, Va., area, with a tongue of moderate to heavy precipitation extending west and south into the southwestern corner of North Carolina. Maximum precipitation reported for the 24-hour period ending 1200 GMT, August 25 during this period of storm development was 2.96 in. at Chapel Hill, N. C.

By 0000 GMT, August 25 (fig. 4A) the surface ridge over New England had weakened further as the pressure falls from the Lake Region moved into the general trough area along the east coast. Deepening was indicated by the increase in area enclosed by the 1012-mb. isobar, as the analyzed central pressure fell from 1010 mb. to 1006 mb.

The 500-mb. Low at the same time (fig. 4B) had begun to turn east and north to follow the surface system northeastward along the coast. Flow over the Chesapeake Bay area at the surface was light east to northeast while that at 500 mb. was moderate south-southwest, an indication of substantial overrunning. Active precipitation was reported at Atlantic City, N. J., Chincoteague and Norfolk, Va., and extending south around the low to Elizabeth City and Wilmington, N. C., and Myrtle Beach and Charleston, S. C. As the Low developed, so did the area of precipitation.

By 1200 GMT, August 25 (fig. 5) the cold front in the Ohio Valley had frontolyzed; there was no thermal definition remaining in the 1000–500-mb. thickness field nor in the surface temperature field. There was, however, still a surface and 500-mb. Low over Lake Erie.

The cold air and cyclonic vorticity with these Lows were now ideally situated to move into the long-wave east coast trough and assist in the retrogression that was necessary to permit the Low to remain near the coast.

Since its formation east of Jacksonville, the east coast

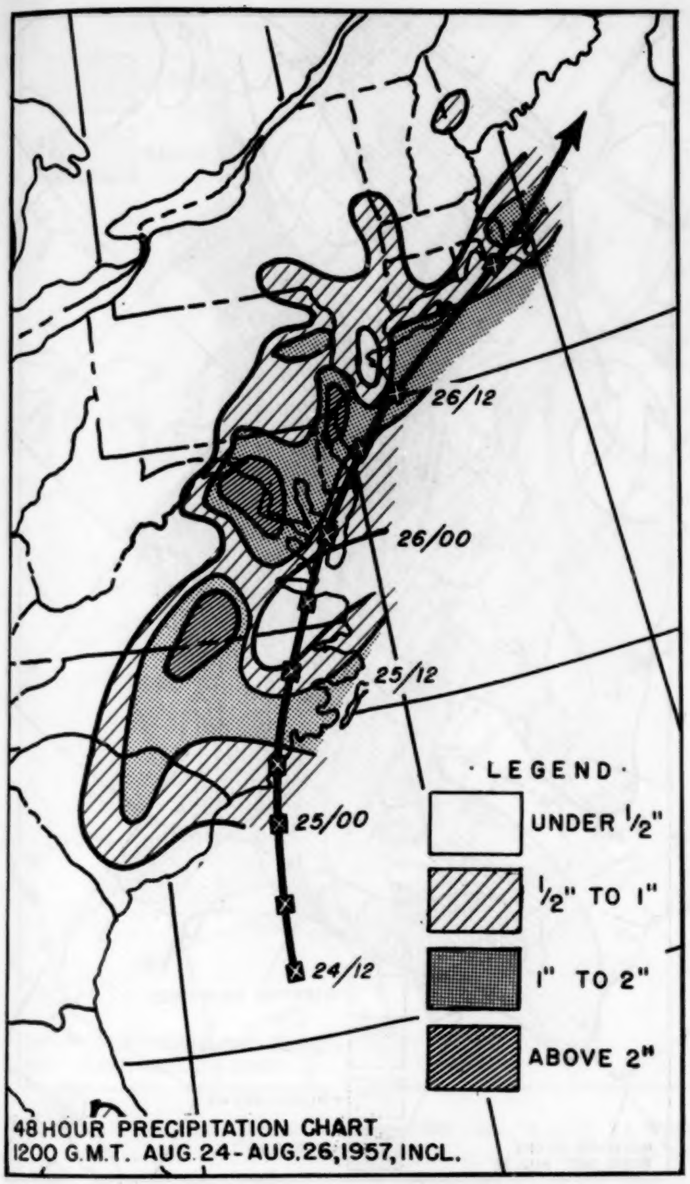

Figure 7.—Precipitation pattern showing total accumulation for 48-hour period 1200 GMT, August 24 to 1200 GMT, August 26, 1957. ⊠ indicates track of surface Low at 6-hour intervals.

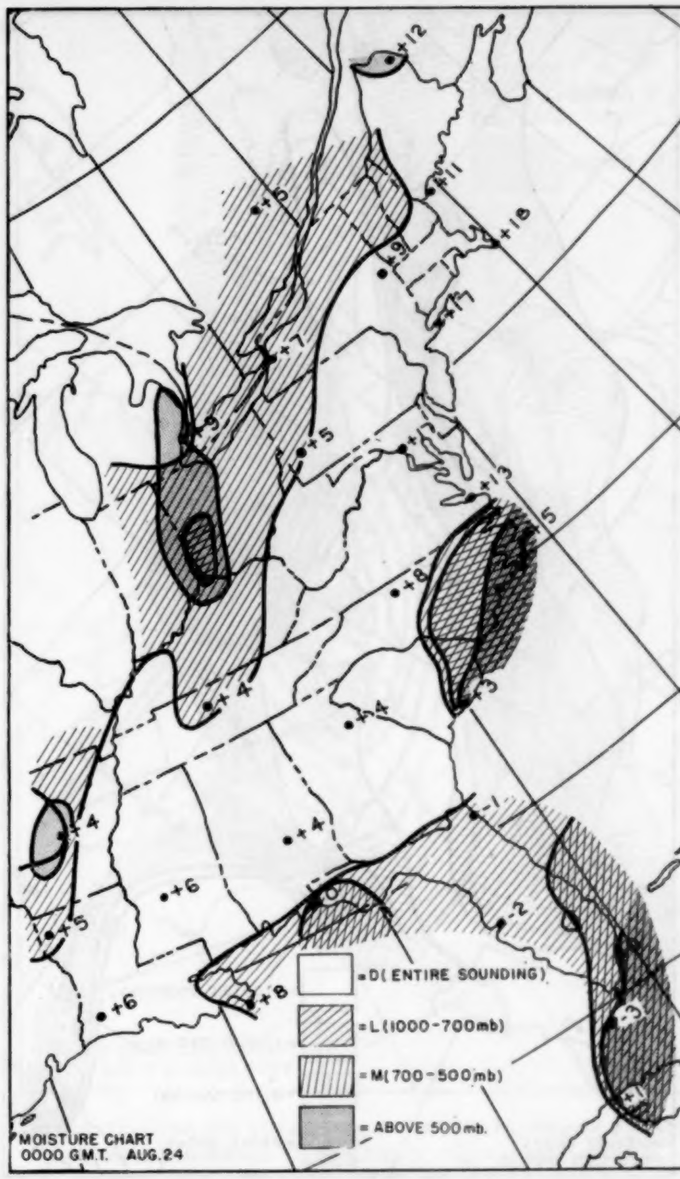

Figure 8.—Moisture chart for 0000 GMT, August 24, 1957. Dew-point depression is indicated by shading and keyed by letter. L=≤4°C. for layer between 1000 and 700 mb., M=≤6° C. for layer between 700 and 500 mb., H=≤8° C. for layer above 500 mb., and D=no single layer meets above criteria. Stability indices are also shown.

Low had moved north with a speed of about 12 knots. Direction and speed were uniform until 0000 GMT, August 26, when the Low was over lower Del-Mar-Va Peninsula. Coincident with its arrival over that area, winds aloft along the coast from Delaware northward had backed to southerly and had increased from 15 knots to 40 knots. Subsequent to 0000 GMT, August 26, forward motion of the storm increased to 15, to 18, to 22 knots, during each successive 6-hour period (averaged over 12-hour period).

By 0000 GMT, August 26 (fig. 6), the surface system had begun to occlude as the 500-mb. Low became more closely associated with it, and the slope between them became more nearly vertical. The surface Low that had been over Lake Erie at 1200 GMT, August 25, weakened further and was overshadowed by the east coast development, while aloft it had depressed the flow over the Ohio Valley and presented an unusual flow pattern, with two closed circulations of approximately equal size, only 5° longitude apart.

The surface Low moved northeastward to merge on August 27 with a Low over northern Labrador, as the trough along the east coast filled in a general readjustment of long-wave pattern over the United States, Canada, and the adjacent oceans.

4. MOISTURE AND PRECIPITATION

Figure 7 is a composite chart of 48-hour rainfall, 1200 GMT, August 24 to 1200 GMT, August 26, 1957 and the

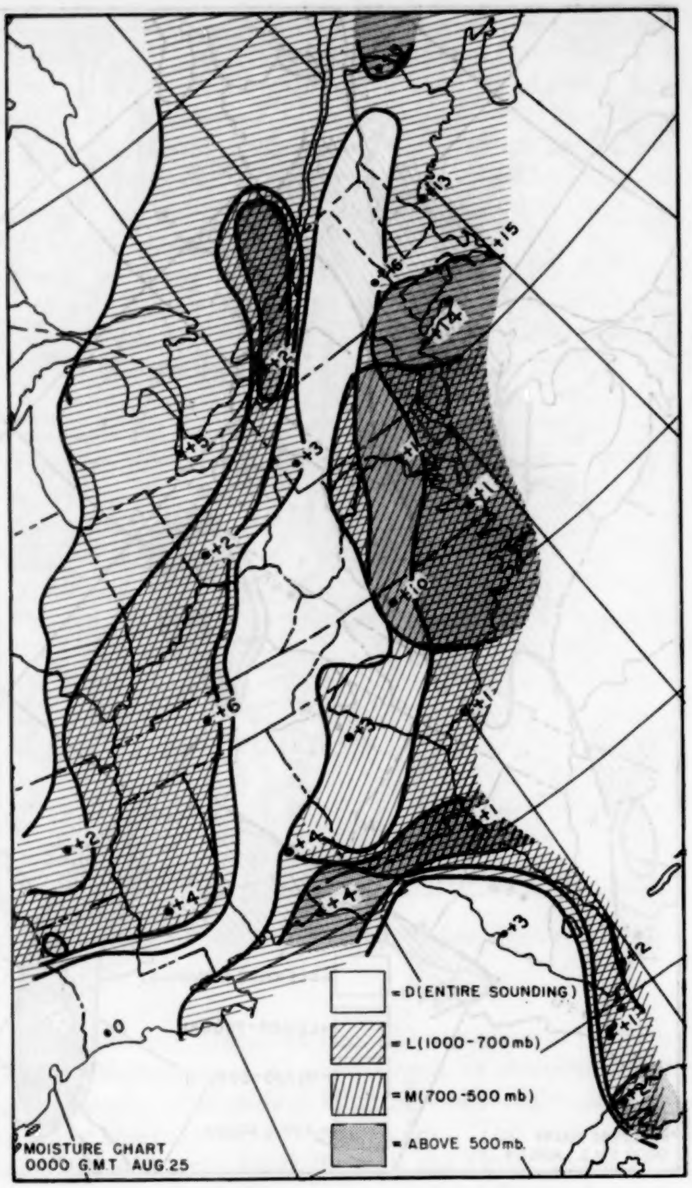

FIGURE 9.—Moisture chart for 0000 GMT, August 25, 1957.

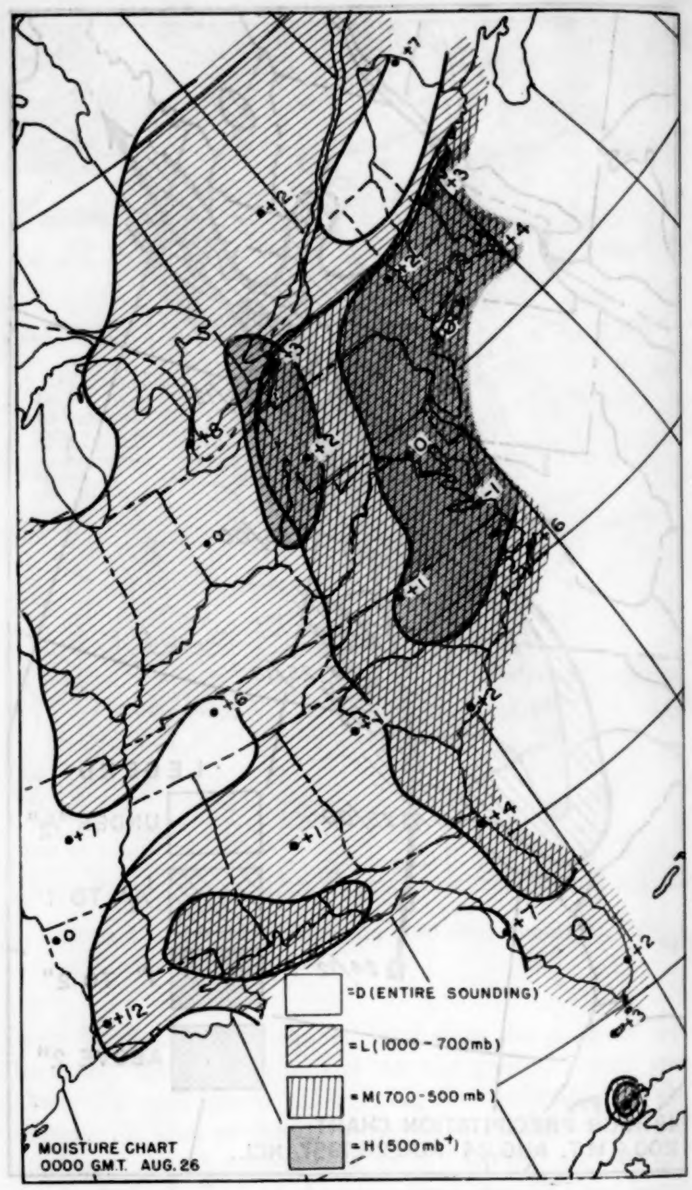

FIGURE 10.—Moisture chart for 0000 GMT, August 26, 1957.

track of 6-hourly positions of the associated surface Low. Development of this precipitation along the Eastern Seaboard has been analyzed only subjectively by means of moisture and streamline charts. An exacting analysis as to cause and effect would be tedious, rather difficult, and too time-consuming for the present purpose. Also, a division of precipitation into its causal classes is not proposed here, except in a general sense into two classes, orographic and non-orographic.

Figures 8, 9, and 10 are charts developed in NAWAC by V. J. Oliver. They represent a subjective approach to portray tropospheric moisture. Stability indices [3] are also plotted on the charts.

The moisture charts, figures 8 and 9, though relative in nature, clearly separate the moisture patterns associated with the east coast Low from the moisture patterns with other systems. Figure 8 shows a wide "dry" belt over the area stretching from Louisiana northeastward to the New England States. The moisture pattern portrayed over the eastern Carolinas and Florida is considered to be part of the system which ultimately produced the drought-relieving rains in the Atlantic Coastal Plain States. Twenty-four hours later (fig. 9) the "dry" belt was still in existence, but not so extensive. Moisture associated with the "system" had spread over the Eastern Seaboard with the greatest depth of moisture extending from central New Jersey southward along the coastal plains to South Carolina. Stability indices had dropped toward zero in the area where greatest moisture depth existed.

Figure 10 depicts the merger of the moisture pattern from the west with that on the east coast as the broad cyclone vorticity field enveloped the whole area east of the Mississippi. The area of greatest moisture depth was, however, still well defined, covering the southern New

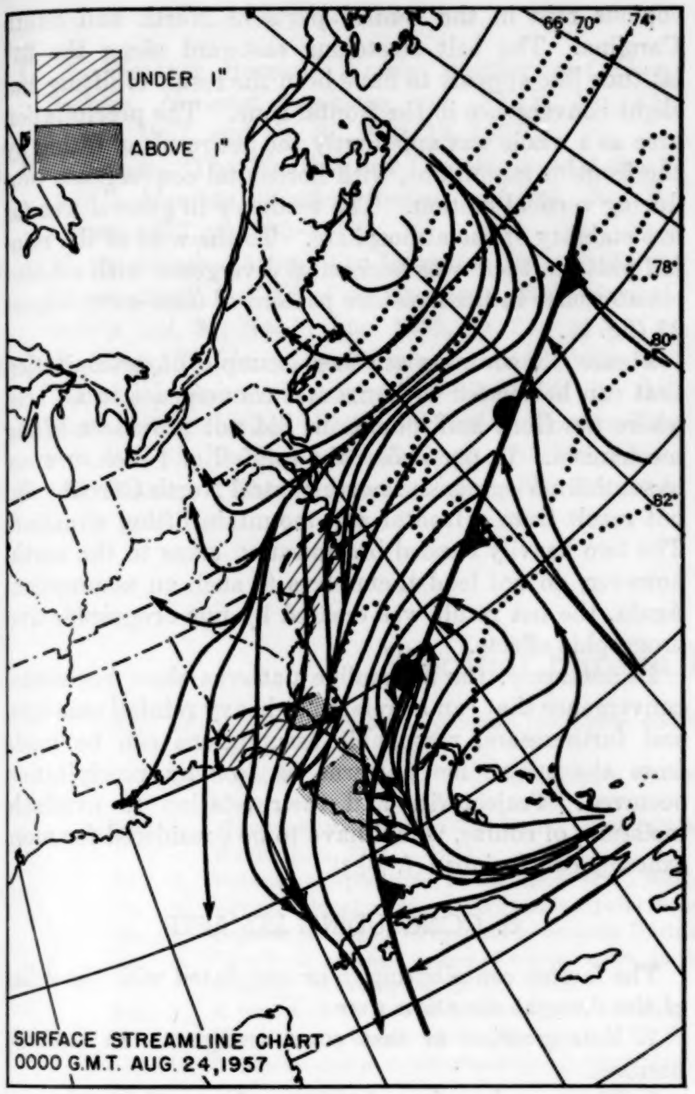

Figure 11.—Surface streamlines for 0000 GMT, August 24, 1957 (solid lines with arrow heads). Hatched area indicates .01 to 1.0 inch, stippled area over 1.0 inch of precipitation for 24-hour period ending 1200 GMT, August 24, 1957.

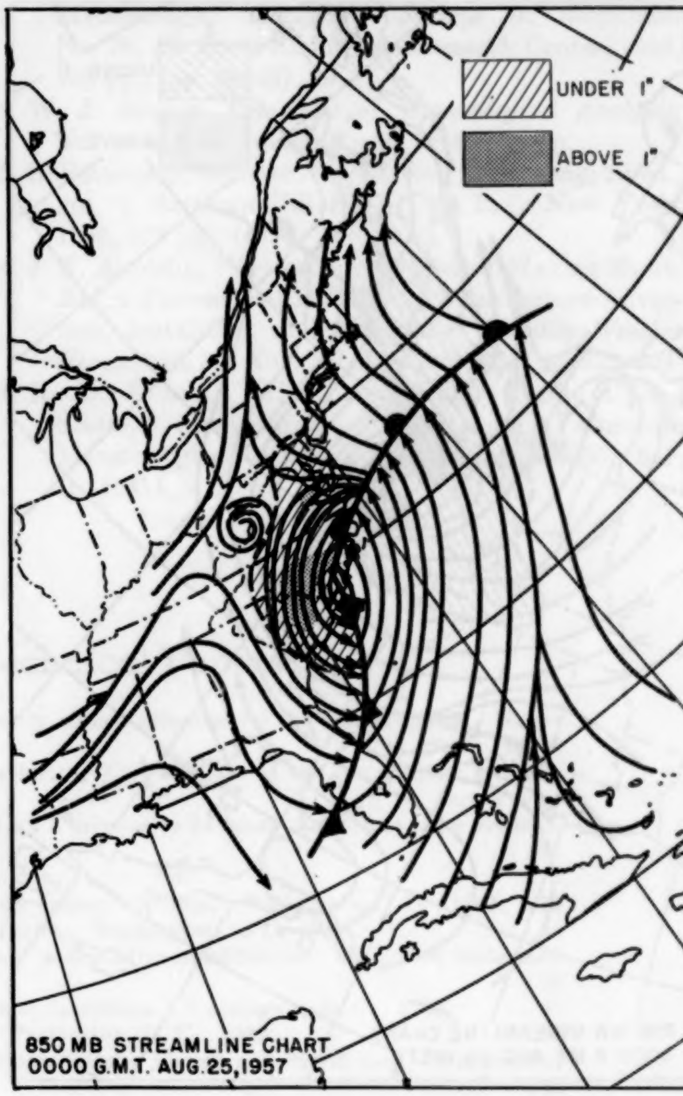

Figure 12.—850-mb. streamlines for 0000 GMT, August 25, 1957. Hatched area indicates .01 to 1.0 inch, stippled area over 1.0 inch of precipitation for 24-hour period ending 1200 GMT, August 25, 1957.

England States southward to the Carolinas and bounded on the west by the Appalachian chain. Stability indices from New York City south were close to zero.

A comparison of figures 8, 9, and 10 with the 48-hour precipitation chart, figure 7, shows that the areas of greatest precipitation were blanketed by areas of maximum moisture depth.

5. STREAMLINE ANALYSIS

The streamline analysis was applied to the surface at the beginning of the period (fig. 11), and carried to a higher level (850 mb.) on succeeding charts (figs. 12 and 13). This was done with the desire to depict that moisture came from low-level sources. Each of these analyses is superimposed upon 24-hour precipitation amounts which bracket the indicated time on the streamline charts. The streamlines were determined by the isogonal method which is described in many articles (e. g., [4]) and books on meteorology (viz: Palmer [5], Saucier [6], and Petterssen [7]).

Surface streamlines for 0000 GMT, August 24 are presented in figure 11. Although streamlines represent the instantaneous flow, there are some conclusions that can be deduced. The pattern clearly depicts a main horizontal convergence zone which definitely contributed to vertical motion. This zone, from Cape Hatteras southwestward to Jacksonville, was centered just off shore. There was a secondary zone running parallel to the sea surface isotherms in the vicinity of 38° N. latitude.

Precipitation amounts coincided nicely with the main convergence zone, and it would be reasonable to assume that this convergence played the dominant role, because the front lay considerably to the south of the convergence zone. The precipitation in central Florida was probably

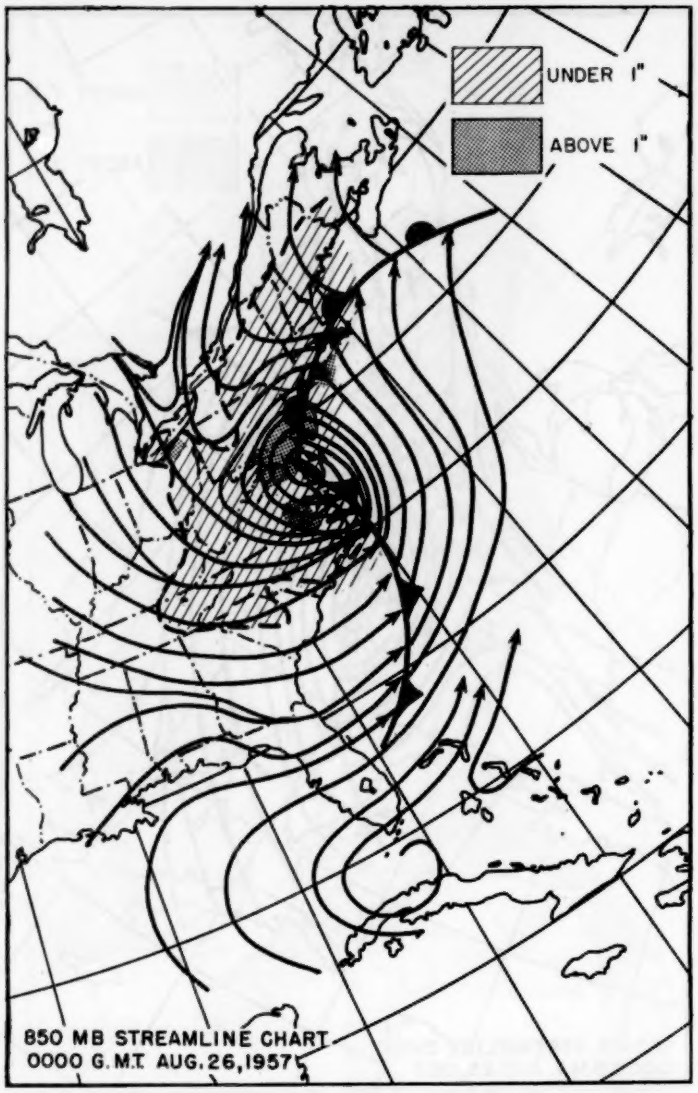

FIGURE 13.—850-mb. streamlines for 0000 GMT, August 26, 1957. Hatched area indicates .01 to 1.0 inch, stippled area over 1.0 inch of precipitation for 24-hour period ending 1200 GMT, August 26, 1957.

due to lifting of unstable air at the front; this is portrayed by the streamlines which indicate flow perpendicular to the front. See figure 8 for stability indices. The streamline pattern over the northeastern part of the map suggests that air in the Maritime Provinces was moving across the Gulf Stream and being warmed considerably in the lower layers. Thus with low-level turbulent mixing and slight converging flow parallel to the Gulf Stream, air in the lower layers mixed through increasing depth. This air arrived in the area of strong convergence with less stability and increased moisture.

The 850-mb. streamline patterns for 0000 GMT, August 25 and 0000 GMT, August 26, are presented in figures 12 and 13. Figure 12 portrays an area of horizontal convergence in the central Carolinas. This vertical motion zone would be difficult to separate into orographic and non-orographic effects; however, the combined effects led to copious rain in the central parts of North and South Carolina. The belt stretching eastward along the 35° latitude line appears to have been the result of lifting and slight convergence in the frontal zone. The precipitation area as a whole was apparently the net result of lifting by the front or mountains, with horizontal convergence producing vertical motion. The tendency in general was for less stability of the atmosphere. To the west of the rainfall pattern, there was horizontal divergence with evident counterparts in the moisture pattern of 0000 GMT, August 25 (fig. 9).

Figure 13 contains another example of precipitation that can be related to horizontal convergence in an area where the front and mountains did not provide a lifting mechanism. In particular, the rainfall of 1 inch or more in southern Virginia and north-central North Carolina did not result from a frontal and mountain lifting situation. The two heavily shaded precipitation areas to the north, however, do not lend themselves to such an assumption. Again, the net result was created by non-orographic and orographic effects.

In summary, the streamline patterns show horizontal convergence that can be related to heavy rainfall amounts, and furthermore, reasonable assumptions can be made from the streamline patterns as to why precipitation occurred. Trajectories and their relation to available moisture, of course, would have to be considered for more exacting conclusions (cf. [8].)

6. CONCLUDING REMARKS

The factors contributing to or associated with the relief of the drought situation were:

1. Retrogression of east coast trough to an onshore position.
2. The supply of moisture made available by an easterly wave merging with a stationary frontal system prior to wave development. (See [6] for discussion of inverted trough.)
3. Replacement of anticyclonic curvature of surface isobars with general cyclonic pattern from Philadelphia southward to Jacksonville.
4. Vertical distribution of moisture to levels above 500 mb.
5. Topographic and frontal lifting associated with horizontal convergence, and horizontal convergence alone, appear to be related to copious rainfall areas.
6. Stability indices in the neighborhood of zero.

Obviously, the many facets of the subject have not been exhaustively pursued, but it is felt that the above statements are justifiable in the light of material presented.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to the staff members of NAWAC for helpful suggestions and the reviewing of the article, and to the Daily Map Unit of the Weather Bureau for detailed drafting of figures.

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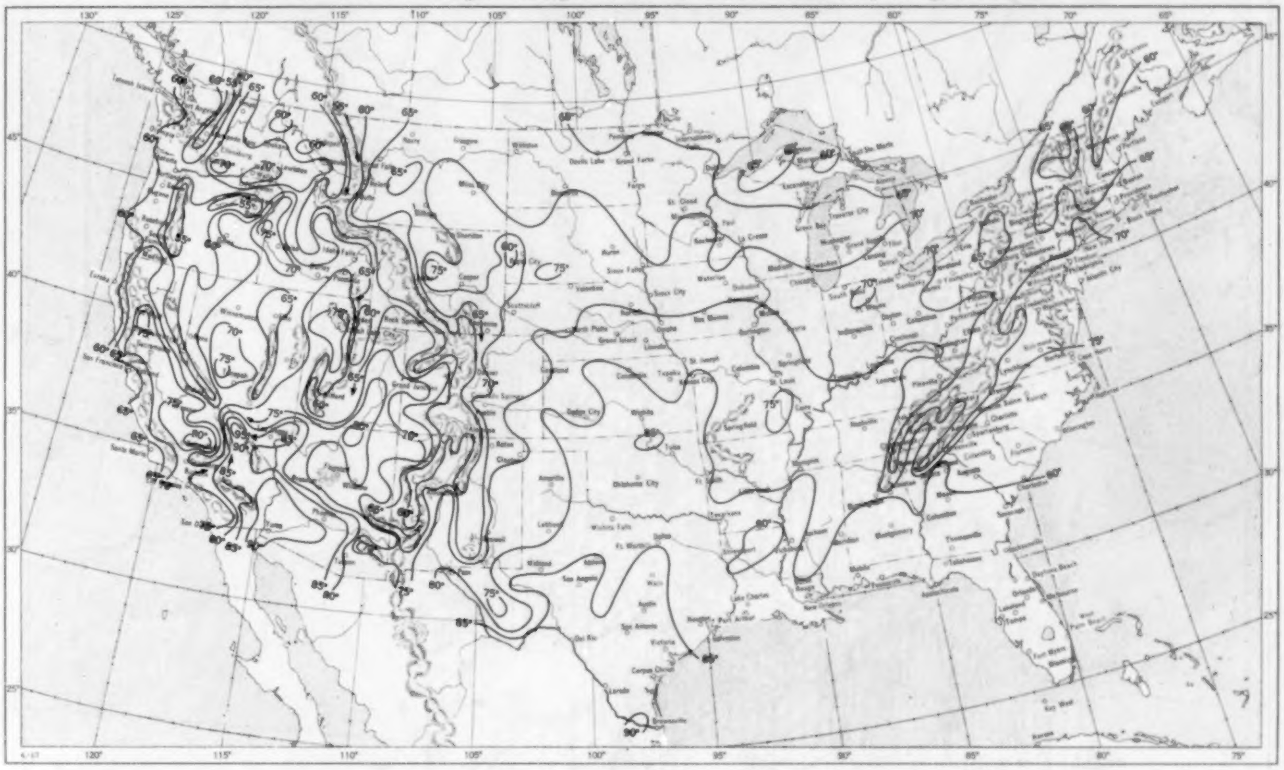
CORRECTION

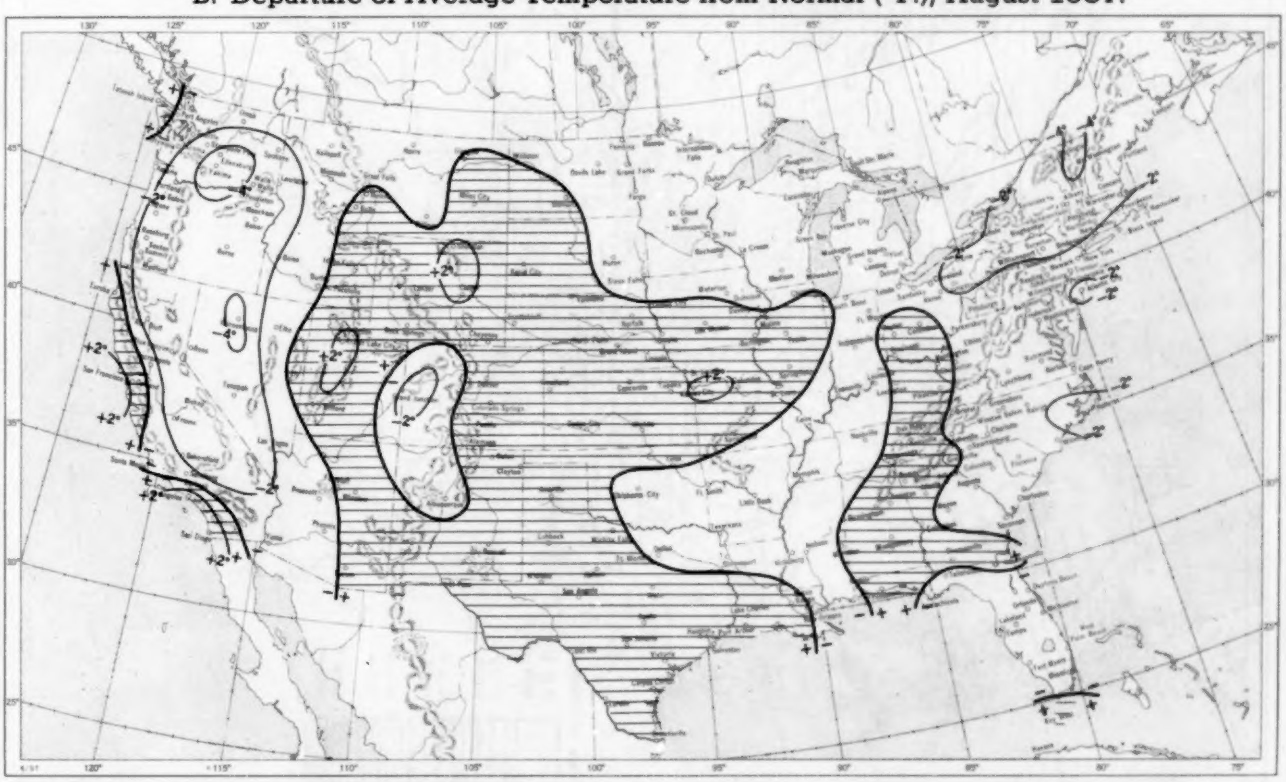
New corrected anticyclone and cyclone tracks (Charts IX and X) for JULY 1957 are included in this issue, following Chart XVII. They should be inserted in the July issue to replace those previously printed and incorrectly labeled July.

U. S. GOVERNMENT PRINTING OFFICE: 1957

Chart I. A. Average Temperature (°F.) at Surface, August 1957.

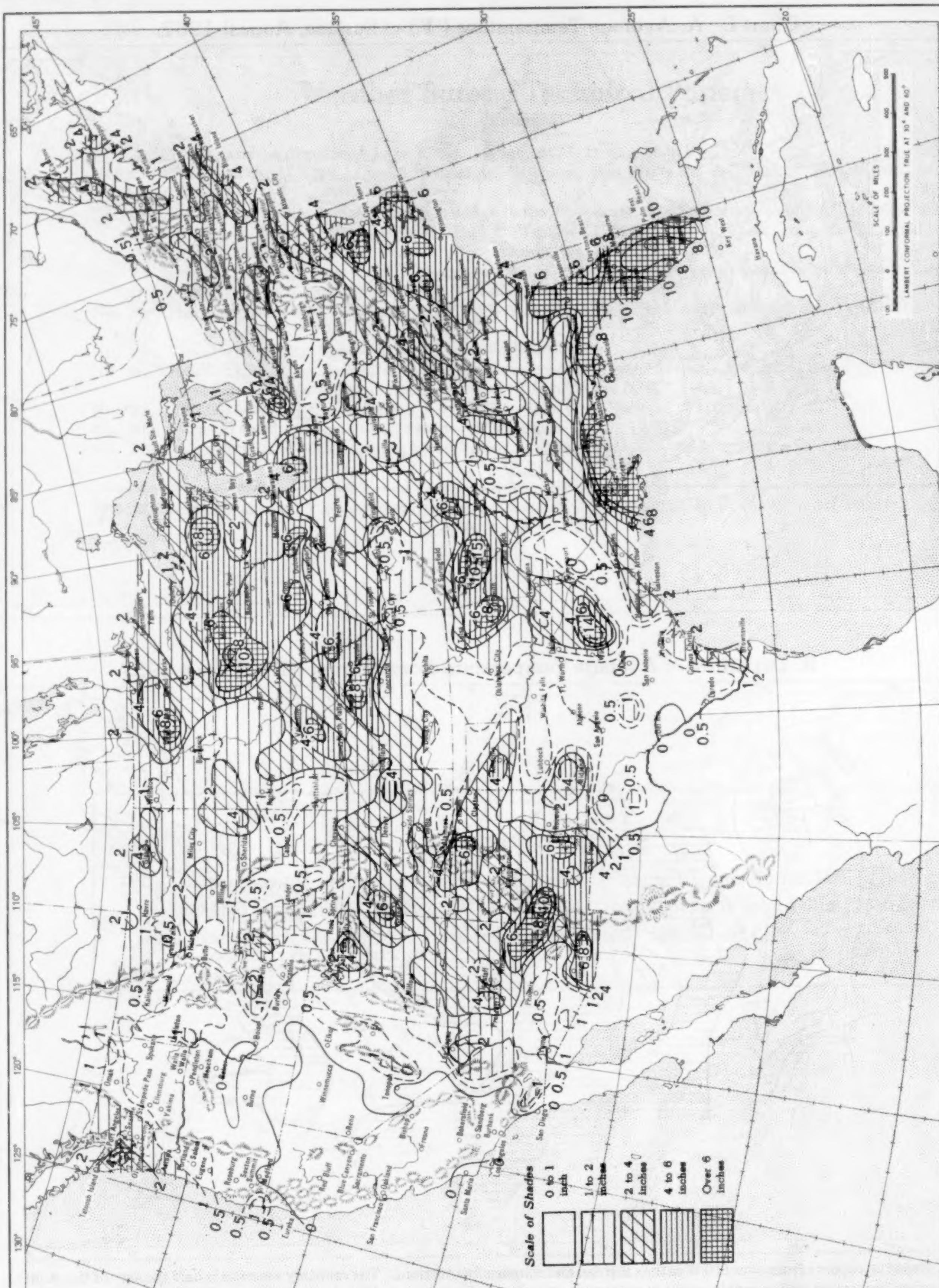


B. Departure of Average Temperature from Normal (°F.), August 1957.



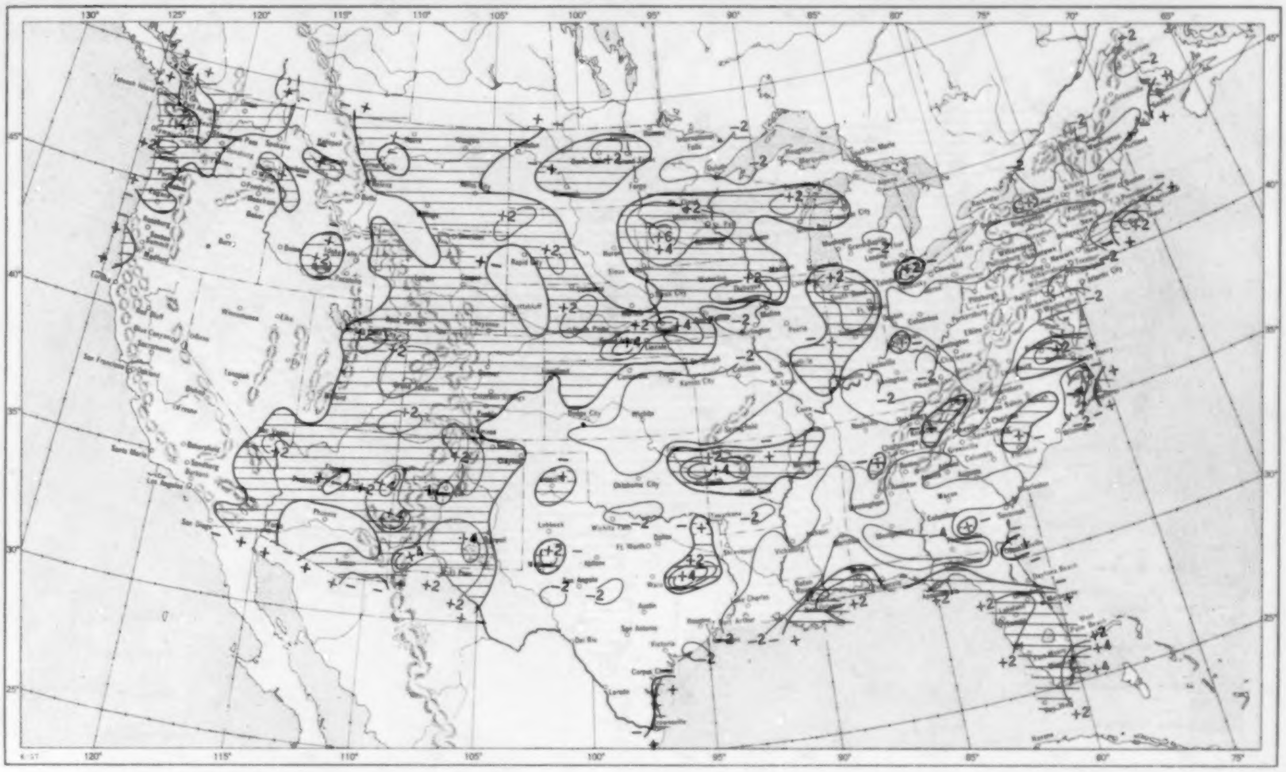
A. Based on reports from over 900 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Departures from normal are based on the 30-yr. normals (1921-50) for Weather Bureau stations and on means of 25 years or more (mostly 1931-55) for cooperative stations.

Chart II. Total Precipitation (Inches), August 1957.

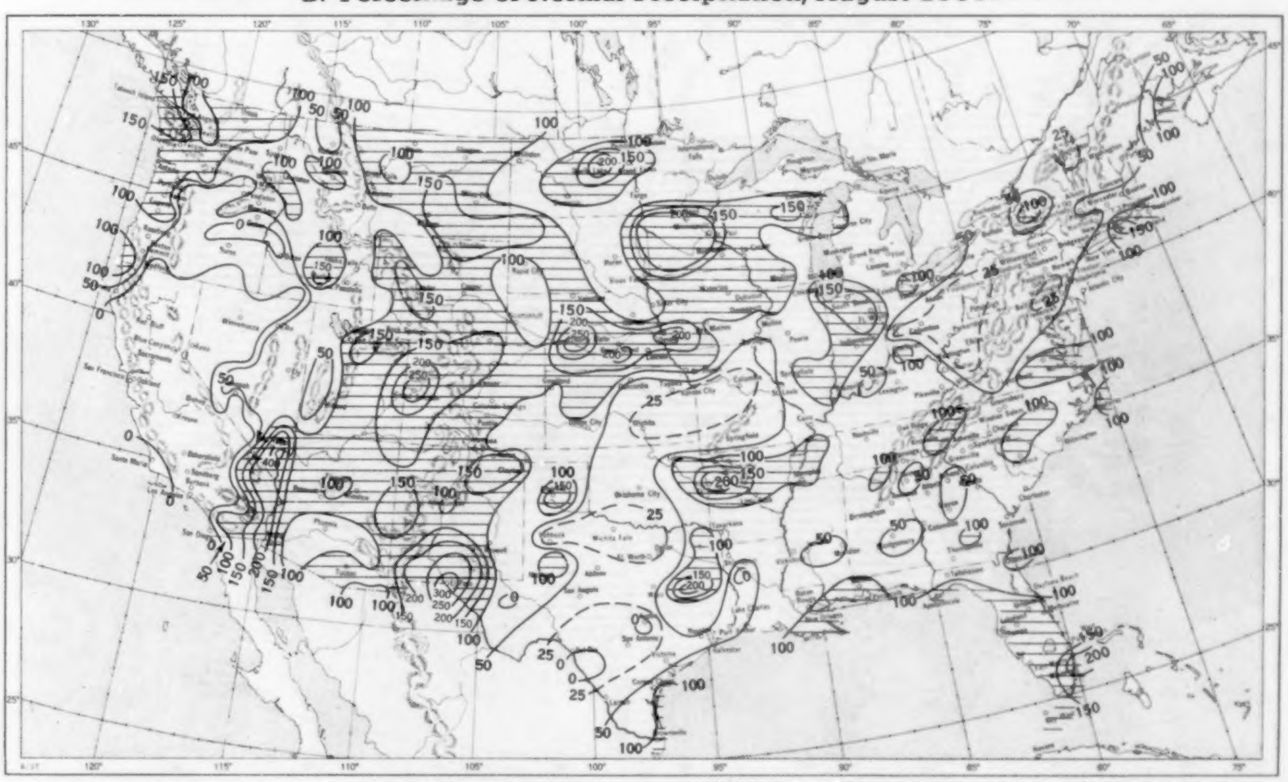


Based on daily precipitation records at about 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), August 1957.

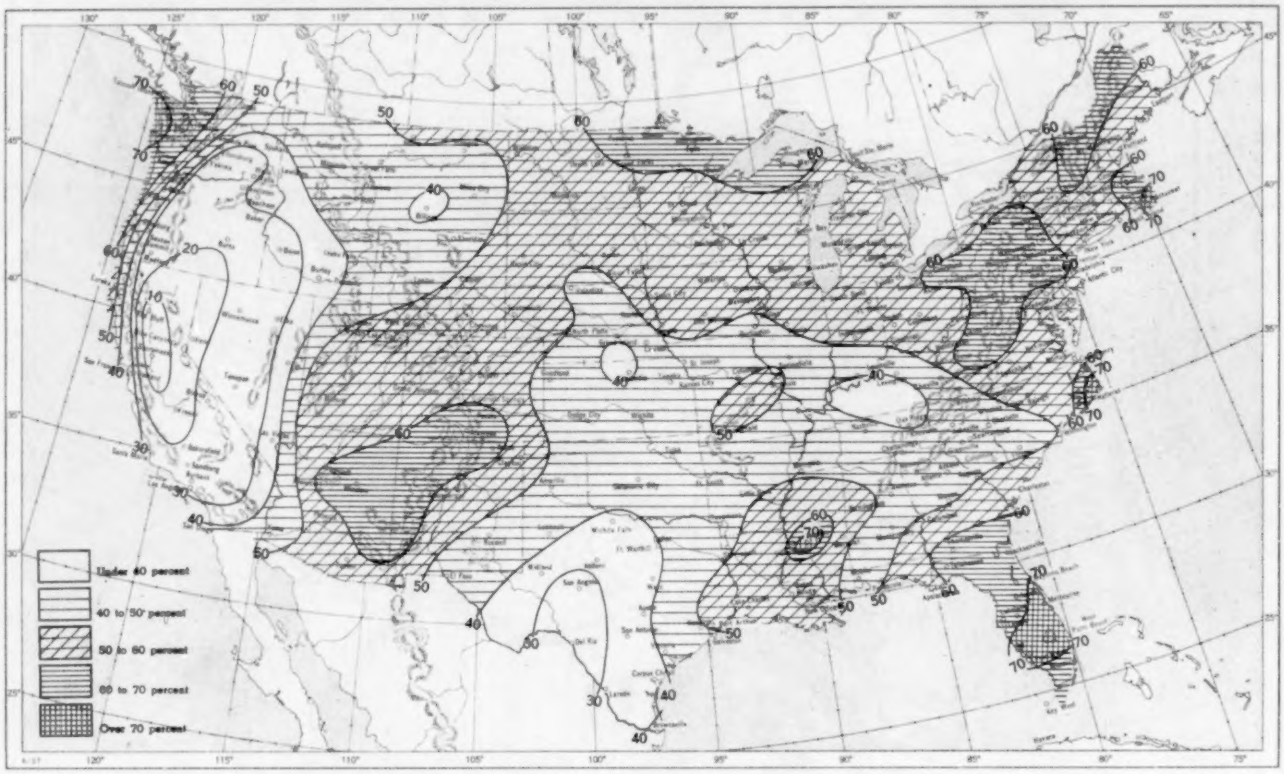


B. Percentage of Normal Precipitation, August 1957.

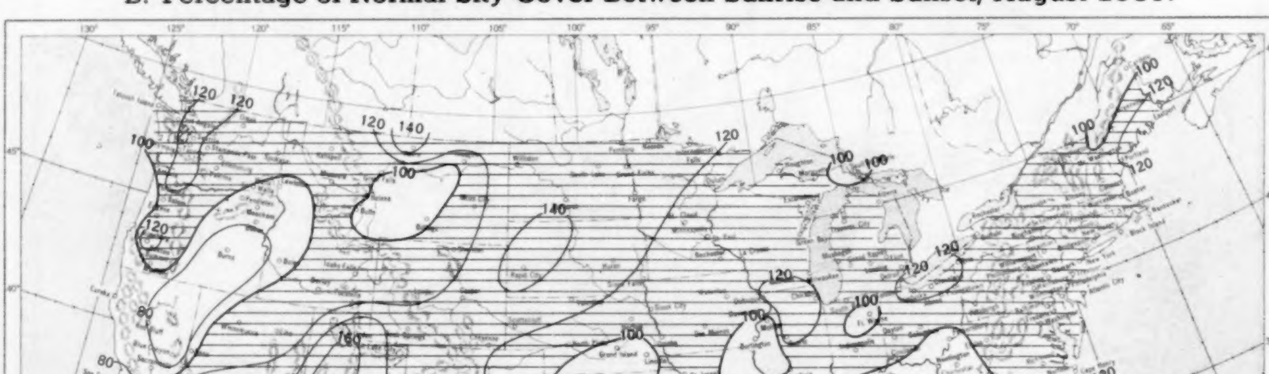


Normal monthly precipitation amounts are computed from the records for 1921-50 for Weather Bureau stations and from records of 25 years or more (mostly 1931-55) for cooperative stations.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, August 1957.

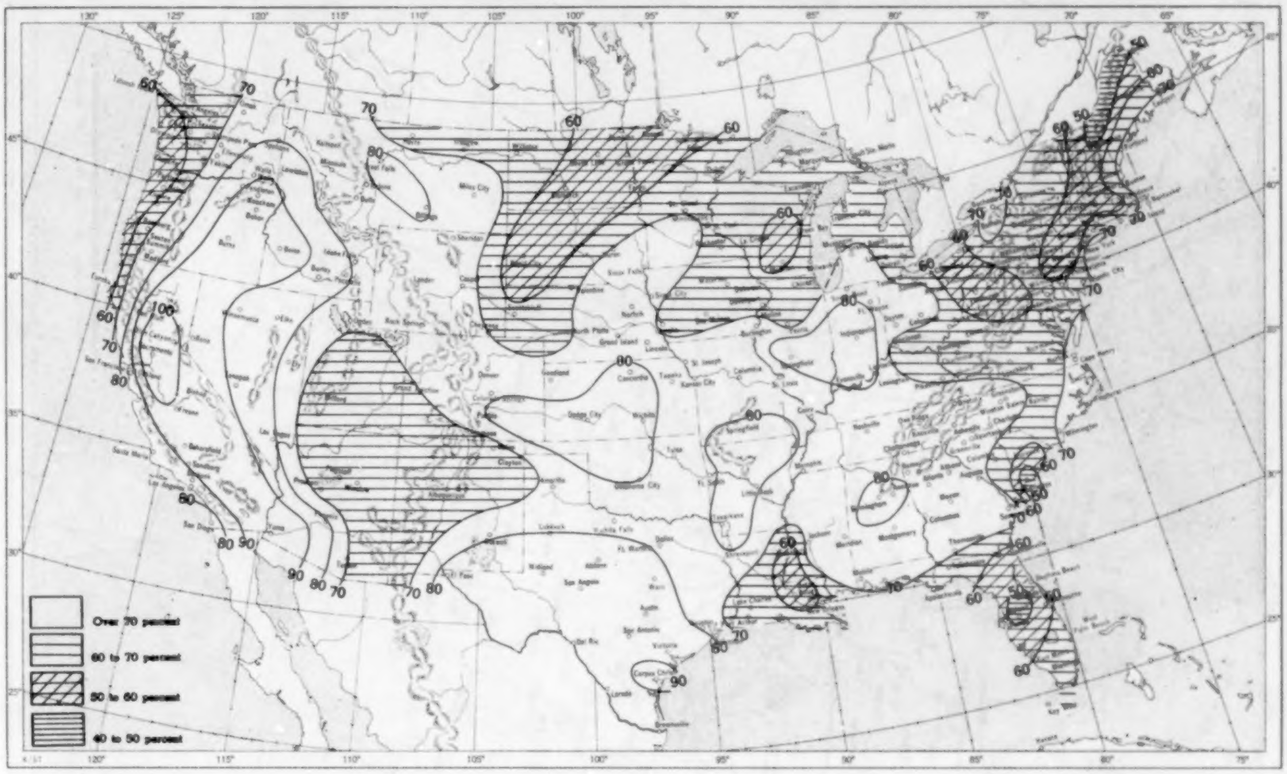


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, August 1957.

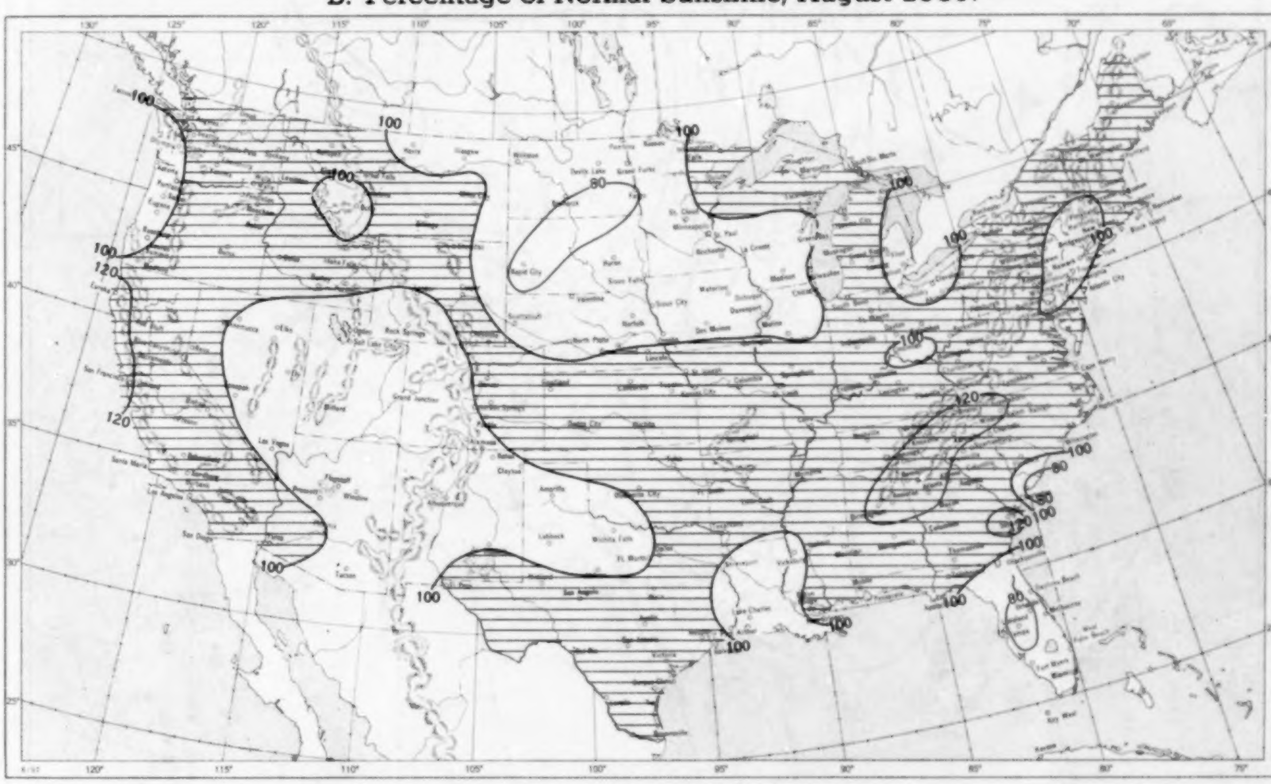


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, August 1957.



B. Percentage of Normal Sunshine, August 1957.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, August 1957. Inset: Percentage of Mean Daily Solar Radiation, August 1957. (Mean based on period 1951-55.)

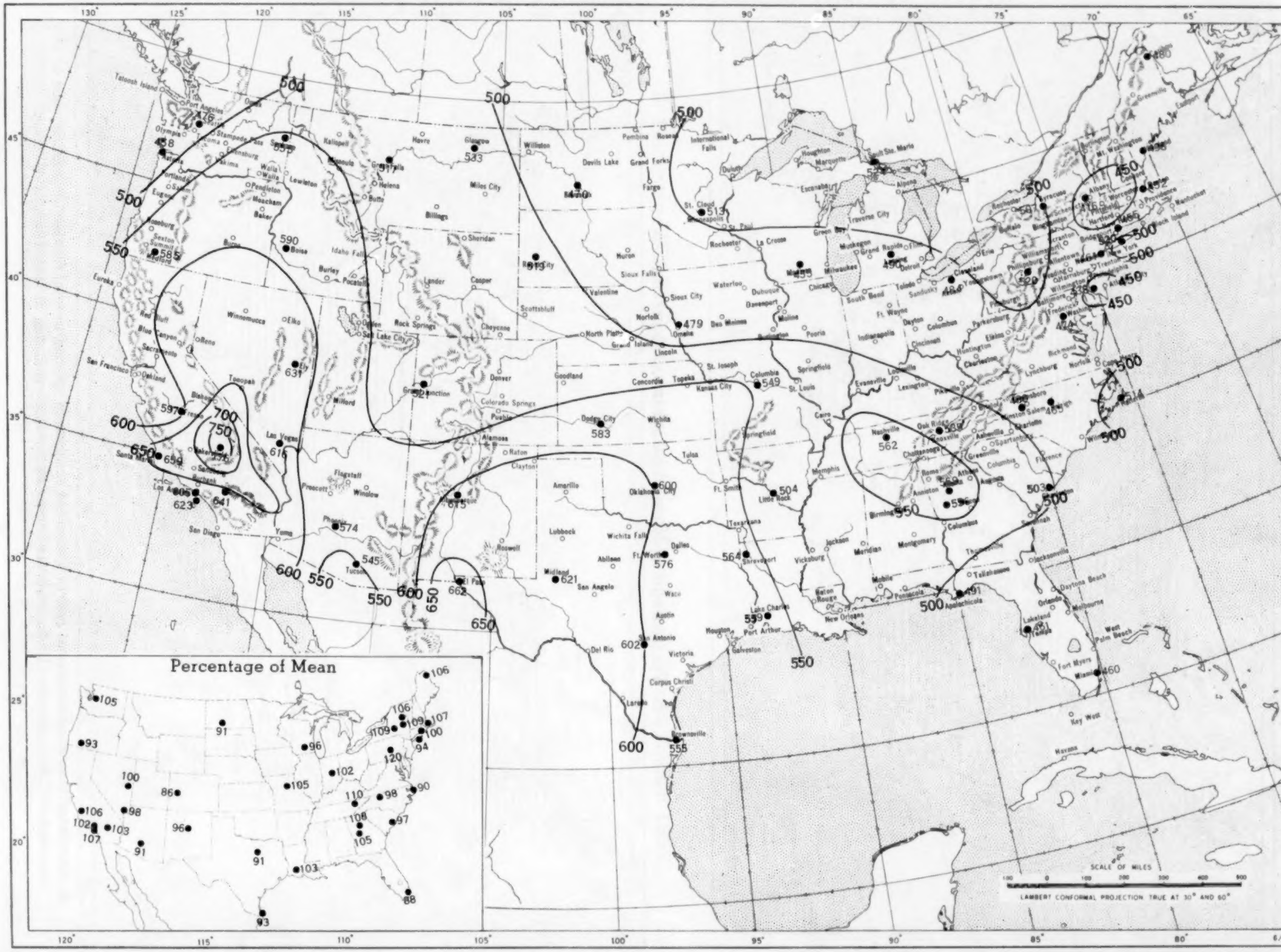
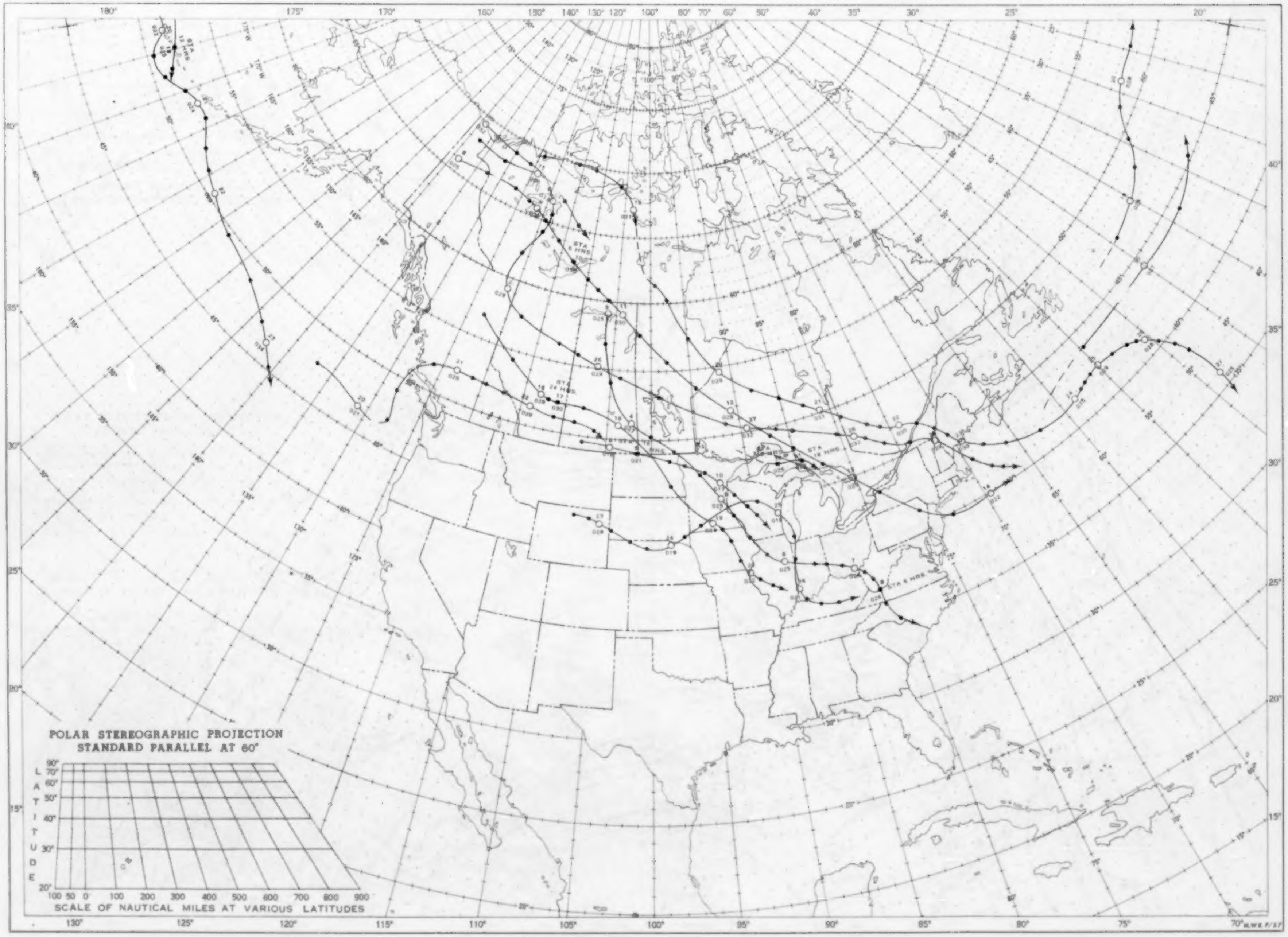


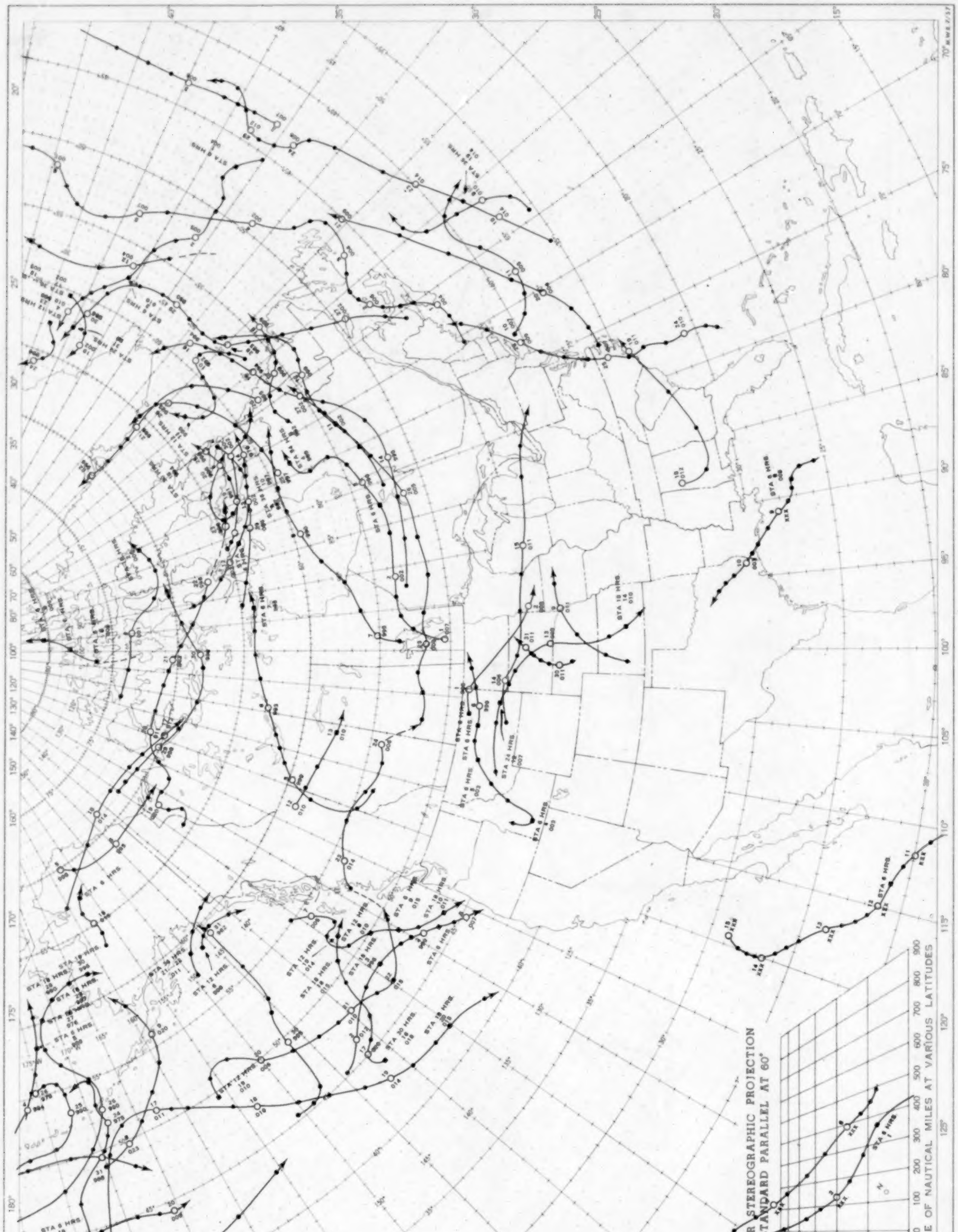
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. The inset shows the percentage of the mean based on the period 1951-55.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, August 1957.



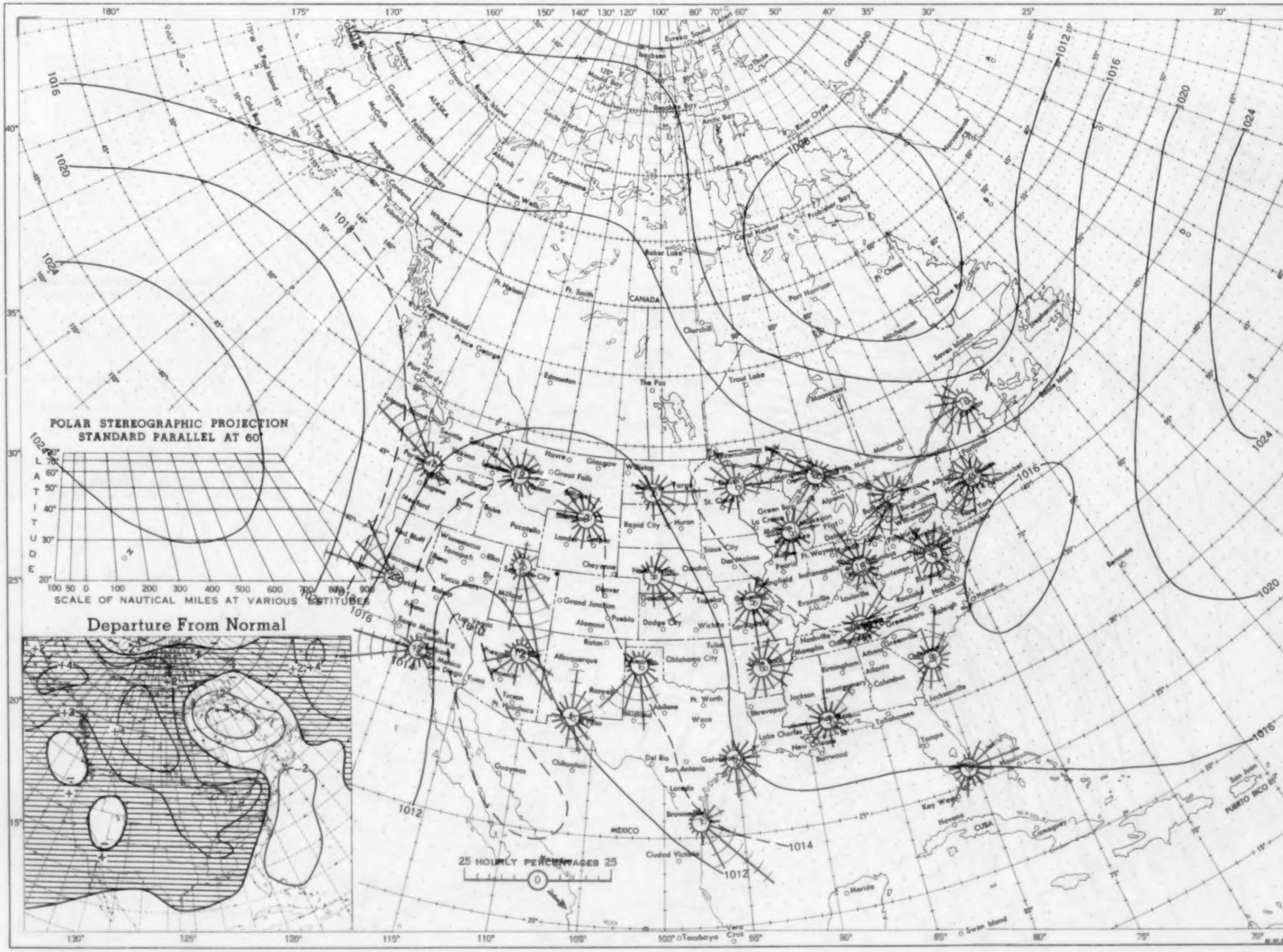
Circle indicates position of center at 7:00 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, August 1957.



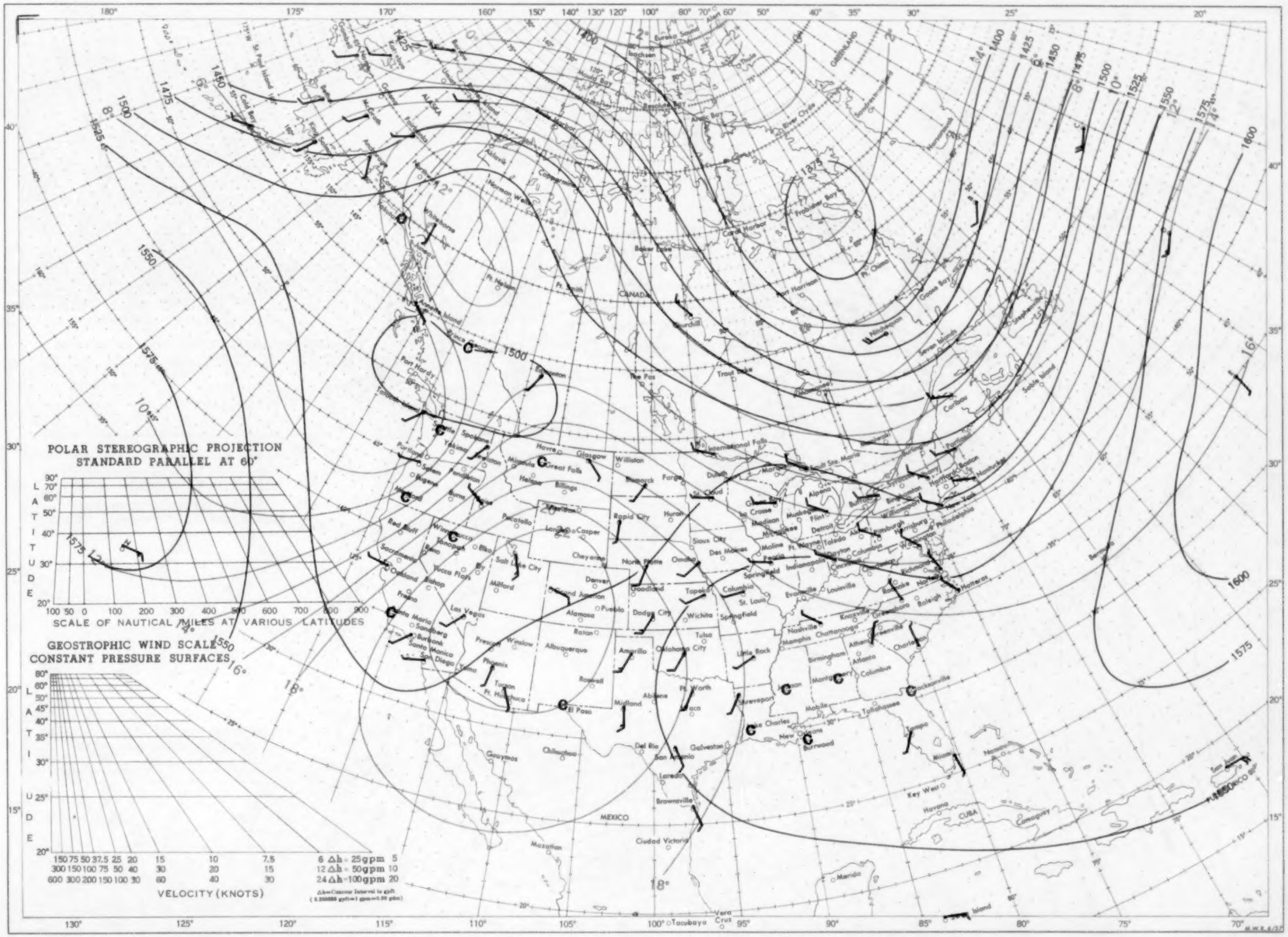
Circle indicates position of center at 7:00 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, August 1957. Inset: Departure of Average Pressure (mb.) from Normal, August 1957.



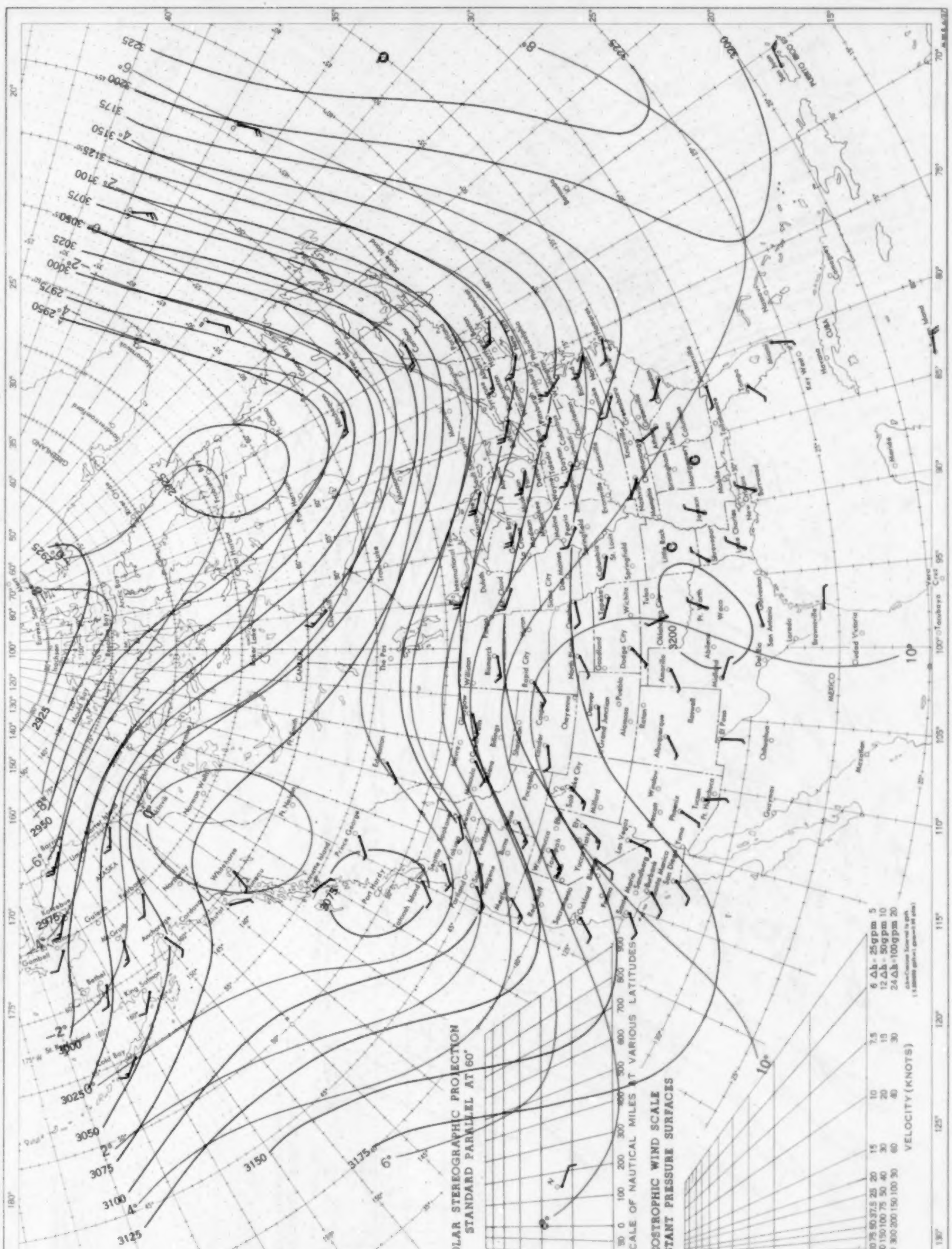
Average sea level pressures are obtained from the averages of the 7:00 a. m. and 7:00 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. 850-mb. Surface, 1200 GMT, August 1957. Average Height and Temperature, and Resultant Winds.



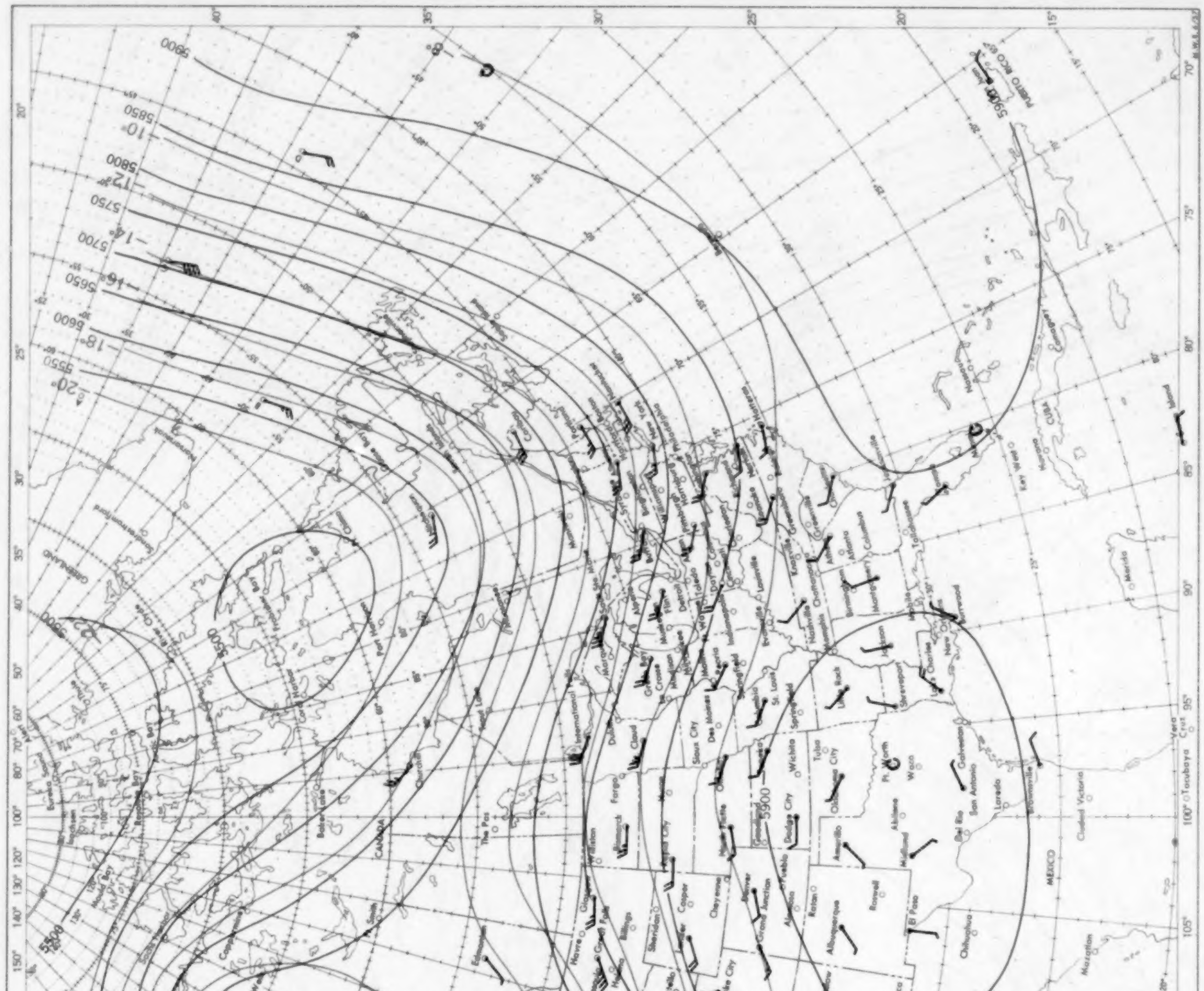
Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. All wind data are based on rawin observations.

Chart XIII. 700-mb. Surface, 1200 GMT, August 1957. Average Height and Temperature, and Resultant Winds.



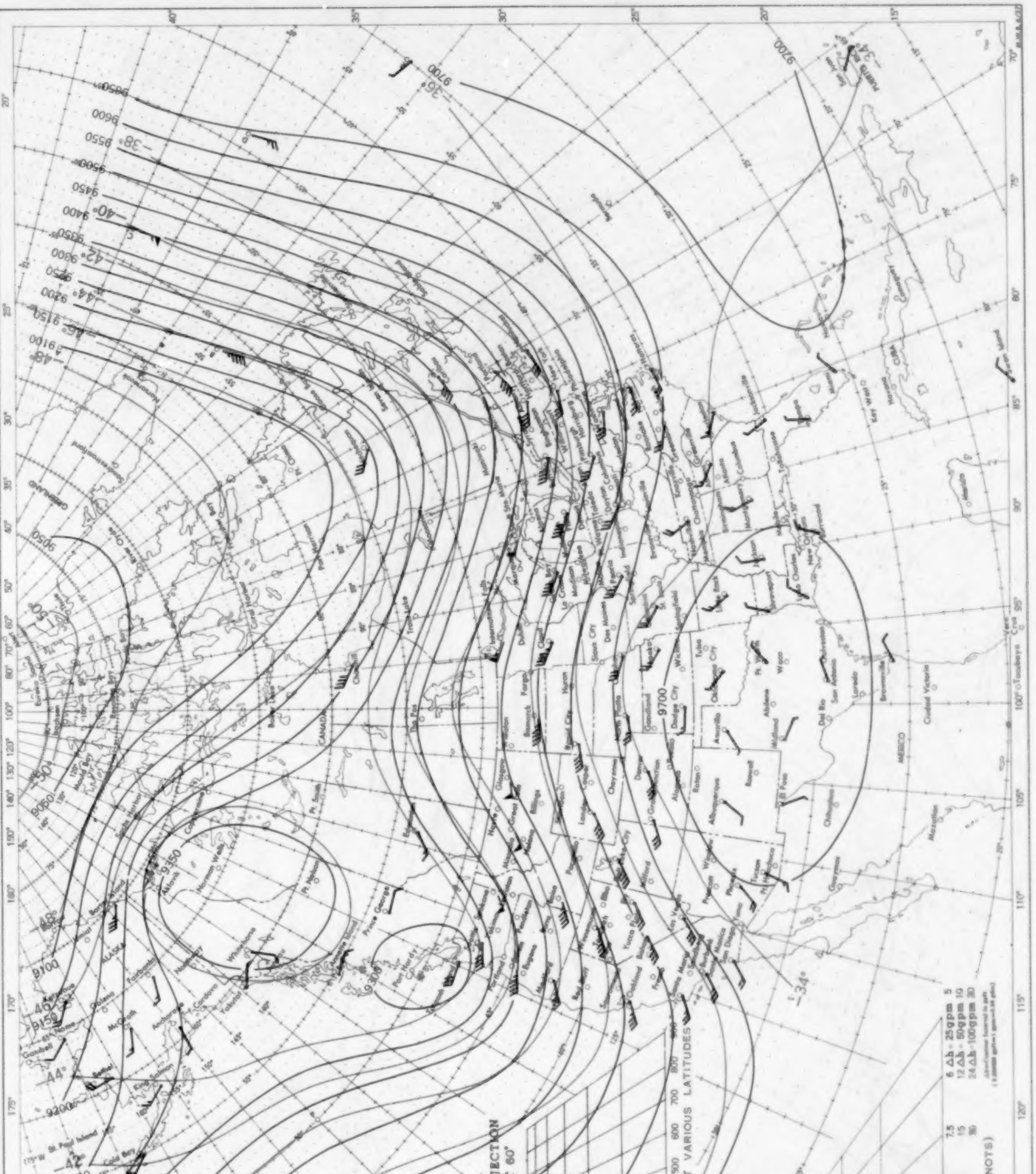
See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 1200 GMT, August 1957. Average Height and Temperature, and Resultant Winds.



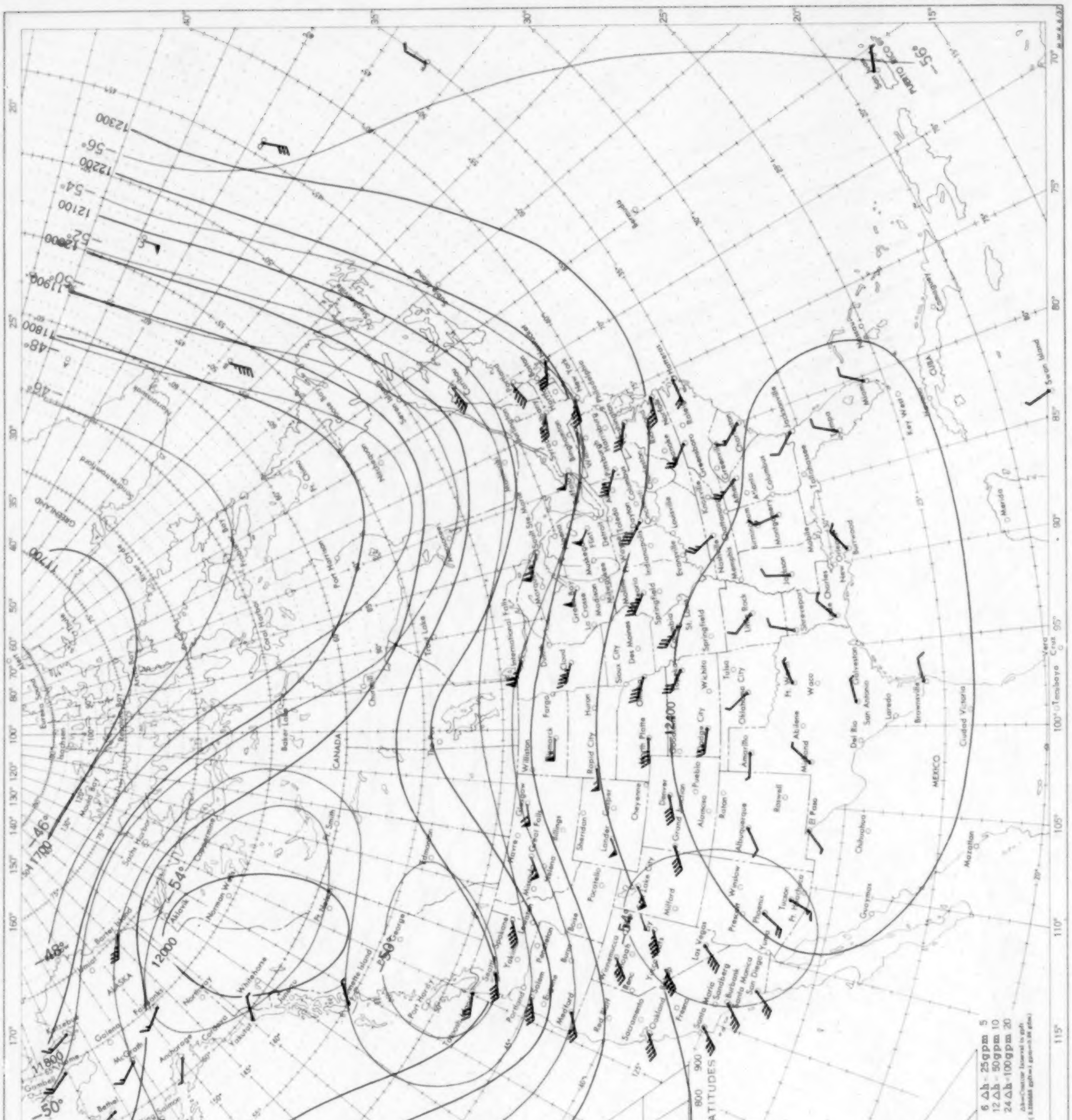
See Chart XII for explanation of map.

Chart XV. 300-mb. Surface, 1200 GMT, August 1957. Average Height and Temperature, and Resultant Winds.



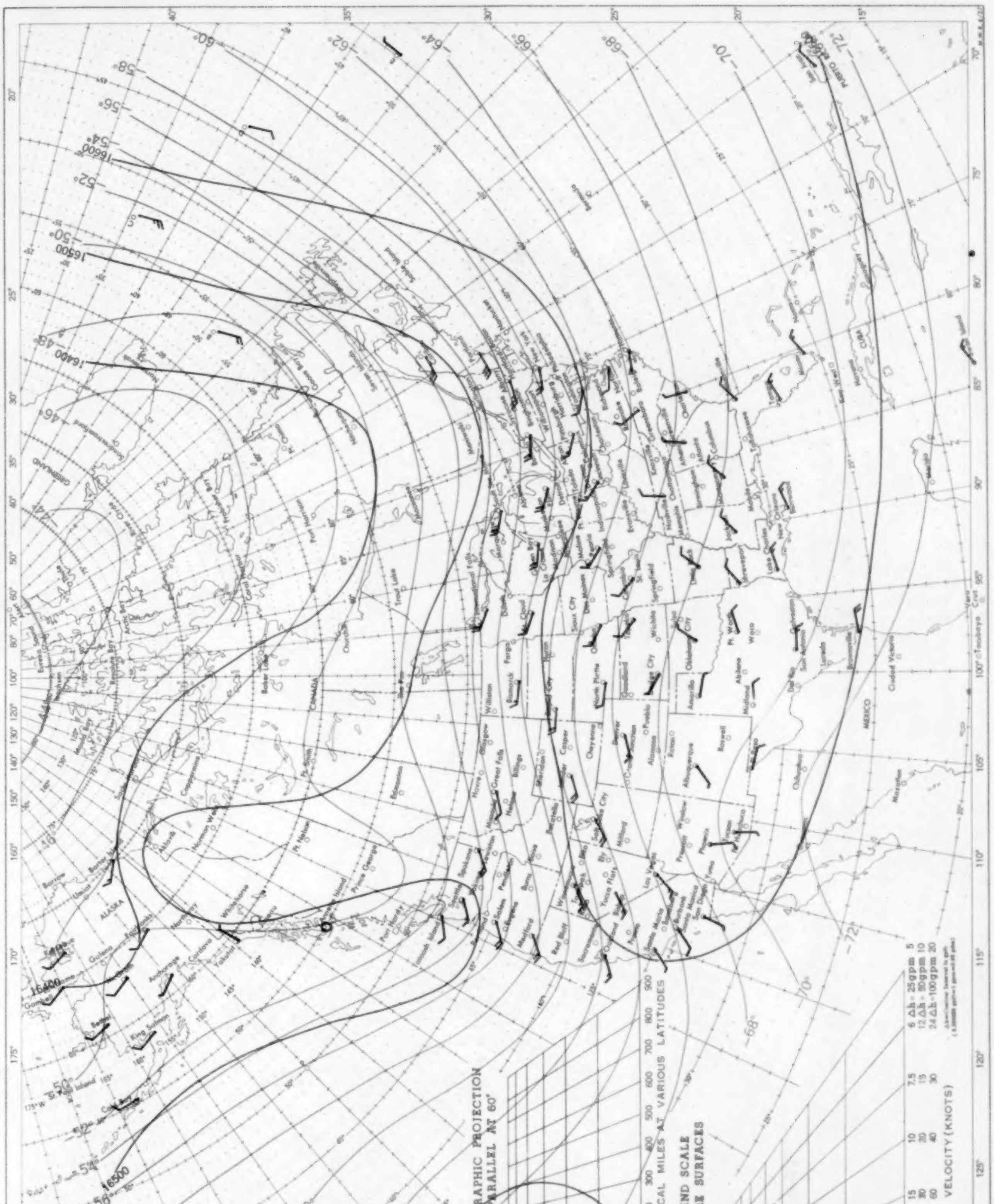
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 1200 GMT, August 1957. Average Height and Temperature, and Resultant Winds.



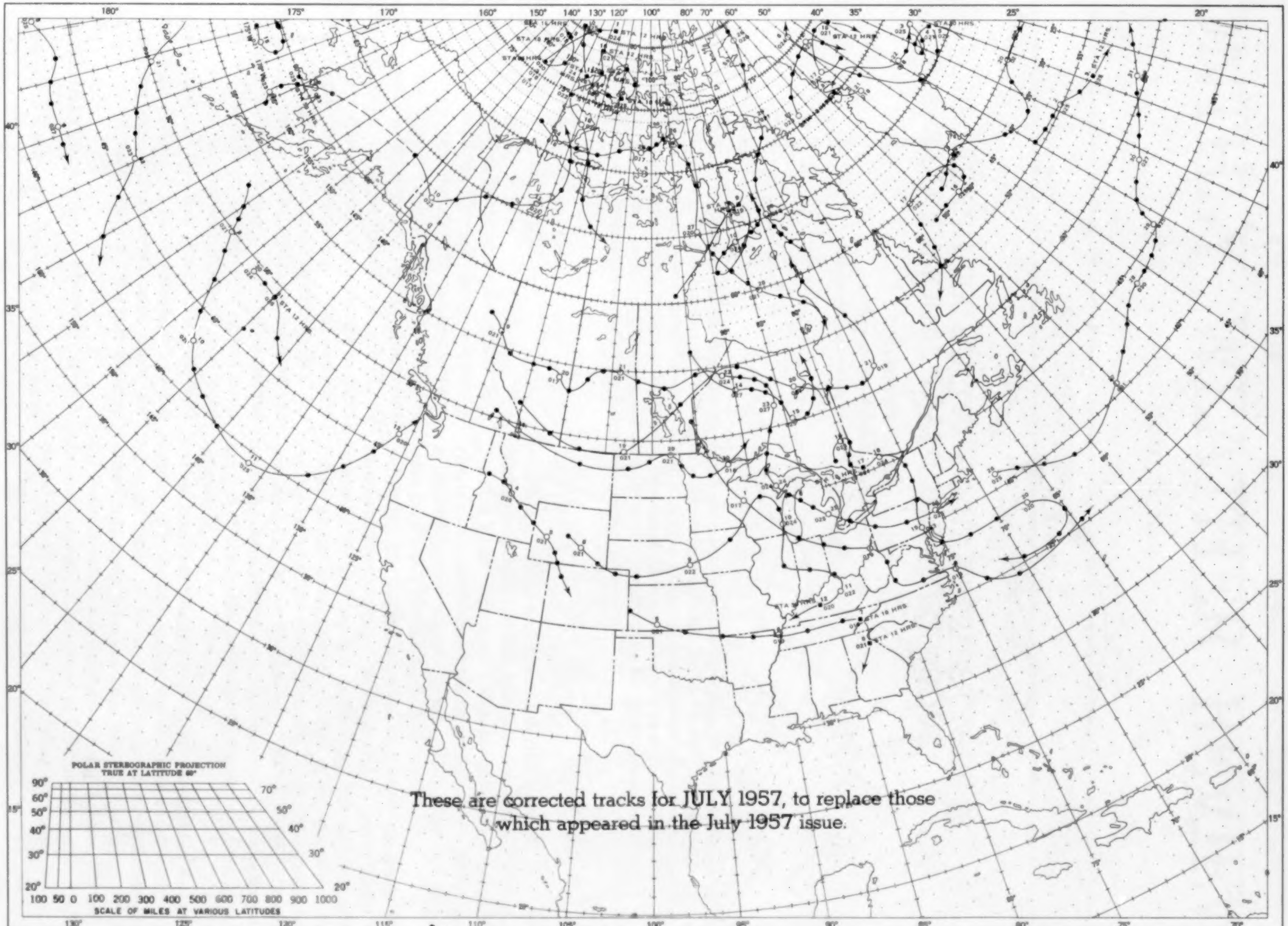
See Chart XII for explanation of map.

Chart XVII. 100-mb. Surface, 1200 GMT, August 1957. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, July 1957.



Circle indicates position of center at 7:00 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.